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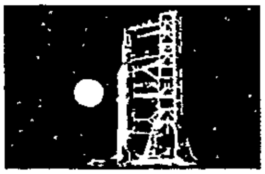
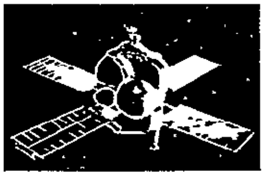



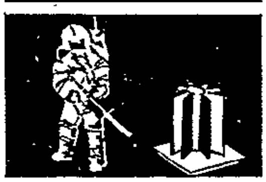
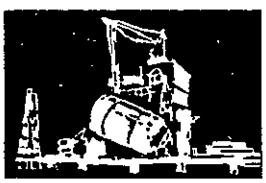

STUDY FOR IDENTIFICATION OF BENEFICIAL USES OF SPACE

(PHASE III)

FINAL REPORT

VOLUME II - TECHNICAL REPORT

BOOK 4 - DEVELOPMENT AND BUSINESS ANALYSIS OF SPACE PROCESSED SURFACE ACOUSTIC WAVE DEVICES

CONTRACT NAS8-28179

NOVEMBER 30, 1975

SUBMITTED PER DPD #451,

DR #MA-04

GENERAL ELECTRIC

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Submitted Per DPD #451, DR #MA-04

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SPACE DIVISION

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PREFACE

The Final Report on Phase III of the Study for Identification of Beneficial Uses of Space (B.U.S.) is comprised of three volumes:

Volume I	Executive Summary
Volume II	Technical Report
Volume III	Appendices

Volume II is further subdivided:

Book 1 - Development and Business Analysis of Space Processed Isoenzymes

Book 2 - Development and Business Analysis of Space Processed Transparent Oxides

Book 3 - Development and Business Analysis of Space Processed Tungsten X-ray Targets

Book 4 - Development and Business Analysis of Space Processed Surface Acoustic Wave Devices

Book 5 - Study Methods and Trade Studies

General Electric's Space Division, under contract from the NASA's Marshall Space Flight Center completed Phase I of the Study in December 1972, and Phase II in December 1973. In Phase III, the Study has progressed to the Business Analysis and Planning for the commercial development and production of the four products in Phase II:

- Surface Acoustic Wave Components
- Transparent Oxides
- High Purity Tungsten X-ray Targets
- High Specificity Isoenzymes

The methodology employed in the Phase III Study and the results of that effort are reported herein.

In addition to Key Individuals from the participating User organizations who contributed specific product, process, business and planning data in each of their respective areas,

the Study Manager acknowledges the outstanding financial and manufacturing analysis contributions of Mr. P. Schmitt, and the considerable contributions of the following: Mr. U. Alvarado and Mr. M. Clarke of the Study Team in analyzing and organizing the wealth of data accumulated; Mr. K. Taylor, the MSFC Contracting Officers Representative (C.O.R.) for the study, in providing key technical suggestions and direction to the overall effort as well as establishing space processing payload guidelines, Mr. G. Wouch, Dr. E. Okress, and Dr. B. Noval of General Electric's Space Sciences Laboratory, in providing supporting space processing data, and Mr. B. Klawans and Mr. F. Curran of General Electric's Systems Operation and Computations Component in programming and processing "INVEST", the interactive profitability analysis program.

As noted in the Final Reports of earlier Phases, publication of this Phase III report neither implies NASA endorsement of any specific product, process or venture identified during this phase of the Study, nor a NASA commitment to pursue any program defined as part of this Study.

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SECTION I
INTRODUCTION

This volume comprises preliminary development plans, analysis of required R&D and production resources, the costs of such resources, and, finally, the potential profitability of a commercial space processing opportunity for the production of very high frequency Surface Acoustic Wave devices. The work reported herein is a continuation of investigations into the space processing of Surface Acoustic Wave devices which have been conducted in Phases I and II of NASA Study Contract NAS 8-28179 (1971-1973).

Technical support for these investigations has been provided by General Electric Electronics Laboratory in Syracuse, N.Y., primarily by

Dr. S. Tehon and

Dr. S. Wanuga,

with contributions by

G. Wouch and Dr. D. Ulrich of GE Space Sciences Laboratory.

The baselines selected for development planning are conceptual, and were established to provide a means of assessing overall technical and economic feasibility under conditions of limited experimental space processing information and very long range market, space facility, and cost projections. These baselines can be expected to change, perhaps even drastically, as later analytical and experimental investigations continue.

I.1 BACKGROUND

Surface Acoustic Wave (SAW) devices have been in use for some time in signal processing functions such as crystal resonators in oscillators and bandpass filters, and as delay lines in volatile memories and circulating integrators. There has been intensive

development over the last 10 years of more complex devices with capabilities of performing entire system functions. A typical device, Figure I-1, consists of a piezoelectric input transducer, an elastic body serving as a mechanical resonator or a storage delay medium, and one or more piezoelectric output transducers. While such components have been built and operated at frequencies below 4 GHz, there is a growing need for equipment to operate at frequencies above 10 GHz, and possibly to 30 GHz.

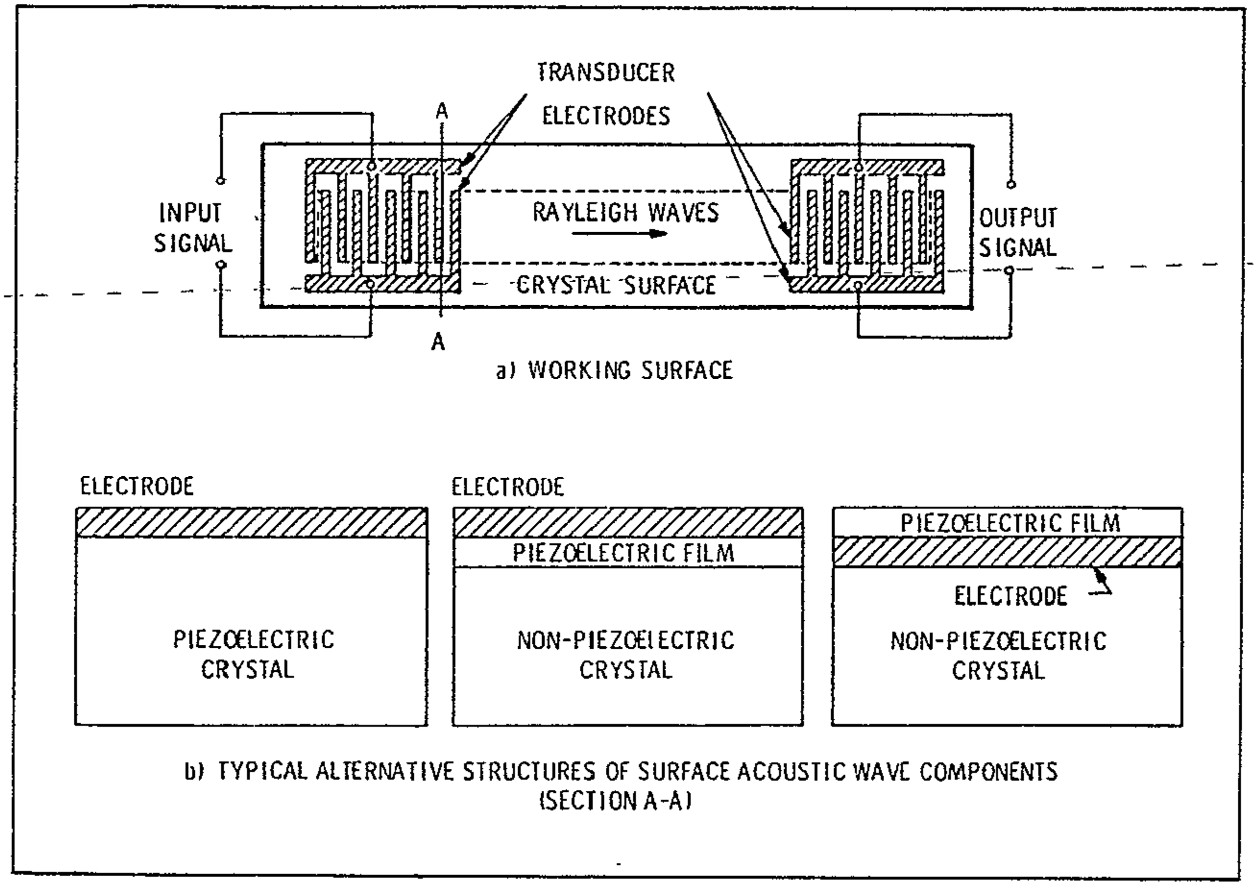


Figure I-1. Fundamental Surface Acoustic Wave Component

A typical 30 GHz SAW device would have a length and width of roughly 2 millimeters, with finger width and spacing as small as 250 A^{O}, and very high crystal quality. SAW devices of 10 GHz would be about 6 mm in length, finger dimensions of 750 A^{O}, and with less stringent (but still demanding) quality requirements.

There are two major problems facing the fabrication of the required 10-30 GHz componentry. In order of difficulty, they are: (1) The imprinting of the extremely fine circuitry on the crystal, now beyond the state-of-the-art for the best printing or photographic processes on earth; and (2) The availability of crystals with the required degree of perfection.

Most earth-grown crystals used for surface wave propagation are Czochralski- or or flux-grown, and frequently suffer from imperfections and inhomogeneities. The encouraging results of crystal-growing experiments on Skylab and Apollo-Soyuz indicate that it may be possible to improve the quality of the needed crystals by growing them in an orbiting environment.

Surface acoustic electronic components currently being produced in ground facilities are limited. Interaction of the terrestrial environment (specifically seismic vibration) with the equipment utilized in imprinting the surface acoustic wave circuitry limits currently ground-produced components to operating frequencies of less than 4 GHz. Various attempts to solve the imprinting problem by isolating the very low frequency vibrations from the imprinting systems have met only limited success in extending the operating frequency. It is felt that isolation from such vibration may be achievable in a properly designed spacecraft facility, thus, perhaps, enabling the use of an electron beam gun in the imprinting process to make it possible to produce the fine circuitry for operating frequencies as high as 30 GHz.

I.2 ASSUMPTIONS

In addition to the basic Study Assumptions reviewed in Section IV of Volume I, the following key assumptions have been made in the development planning:

- The experiments and tests, defined in Phase II and updated in this Phase, will result in successful techniques for growing crystals of extreme perfection from materials suitable to surface acoustic wave applications, and for imprinting the high accuracy circuitry through operation in a space facility free of vitiating low frequency vibrations.

- Shuttle/Spacelab services will be available to meet development requirements.

- In-space power requirements for crystal growing and imprinting circuits (20-30KW peak) will be available as needed.

- The availability of an on-orbit Surface Acoustic Wave processing facility, not requiring launch and recovery for each production flight was a late assumption in the Study, and is discussed in Volume I, Section IV.1.

- An initial Study Guideline (Section IV.1, Volume I) directed that our profitability analysis assume that each user bear the full cost of developing the space process utilized for producing his product. All four of the products under study were unattractive ventures under the combination of this assumption and derived economic data. The NASA C.O.R. suggested that this combination be noted as "Case A".

  He further suggested that, since basic processes would have broader application than the individual products under study, it could likely be assumed that basic process proof-of-feasibility would be carried out under government funding. Users, therefore, would only bear those R&D costs that specifically provide prototype/pilot plant capability. The combination of this assumption and the same derived economic data as in the prior case is called "Case B". While some financial measures were very attractive in Case B, the "breakeven point" was still not favorable, and further assump-assumptions led to "Case C". Assumptions for Case C include these of Case B, plus a 50% increase in unit price. The uniqueness of the product makes that alternative a viable possibility. An unexplored possibility is that of a possible decrease in unit manufacturing cost, if a solar concentrator system for melting crystal materials becomes available. Such a facility could lower the manufacturing costs by an estimated 5 to 10%.

I.3 PRODUCT OBJECTIVES

The product objective is to utilize the "zero gravity" of the space environment and isolation from earth disturbances to enable the growth of high perfection cyrstals, and the fabrication of x-ray lithography masks to be used in the production of Surface Acoustic Wave devices. Such devices will be fabricated of wafers sliced from the space-grown crystals, with circuit elements imprinted at a spacing of 1/4 to 1/2 wave length. A typical goal for a Surface Acoustic Wave (SAW) device to operate at 30 GHz

is a crystal wafer of 2 mm length, on which is imprinted a circuit of 36,000 elements, each of which is .1 mm long by 250 A^o wide, with an accuracy of $\pm$20 to 25 A^o.

Required crystal perfection is beyond current production capabilities and the imprinting process for very high frequency circuits (10 - 30 GHz) is beyond the state-of-the-art for the best printing or photographic processes on earth. The overall objective, therefore, is to avoid earth vibration and other effects which limit Surface Acoustic Wave devices to below 10 GHz, in order to meet a need for 30 GHz and higher frequency capability which already exists.

I.4 PROCESS ALTERNATIVES AND BASELINE

The alternative process methods and key steps in the baseline approach selected for this Phase of Study have been derived in Phase II. These are shown in Figure I-2. Those major alternatives and decisions left unresolved in Phase II, due to lack of critical phenomenological or process data, have for the most part, been resolved by assumptions for purposes of this phase of study. It must be noted, however, that a high degree of judgement has been exercised in making the required selection.

It should also be noted that a key conclusion of Phase II was that there were several process steps for which the orbital environment offered no significant advantages, but for which space operations would be preferred in order to simplify the overall process. As the Phase II Study progressed through cost and value analyses, it became evident that these preferential selections could not be justified economically. The process approach in Figure I-2, therefore, has been modified from its initial Phase II notation to conform to the change in decisions on those process steps.

The technical decisions and unknowns associated with this selection are given in Figure I-3. This figure, too, reflects the above-noted changes.

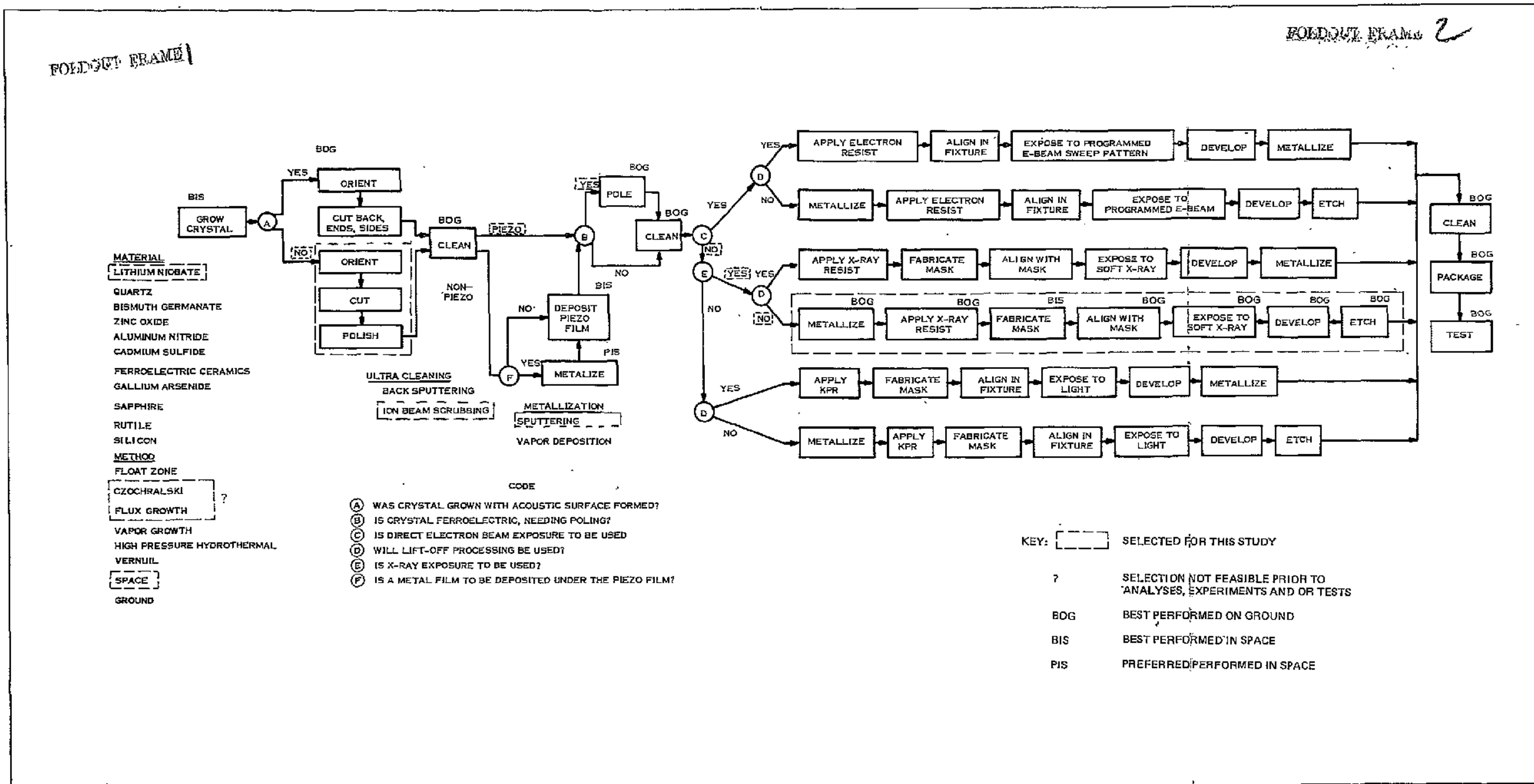


Figure I-2. Best Implementation Approach for Fabrication of Surface Acoustic Wave Components

Decision Area	Baseline Method
1. Choice of crystal material	Lithium Niobate
2. Choice of crystal growth environment	Space
3. Choice of crystal growth method	Modified Czochralski Pulling (?) Fused Solvent (?) Modified Bridgeman Technique (?)
4. Choice of melt retention method	?
5. Choice of crystal cut/polish method	Orient, slice, cut, and polish surface, back, sides, and ends
6. Choice of crystal cut/polish environment	Ground
7. Choice of crystal pre-cleaning environment	Ground
8. Choice of cyrstal ultra-cleaning environment	Ground
9. Choice of crystal ultra-cleaning method	Ion beam scrub
10. Choice of surface metalization method	Sputtering
11. Choice of surface metalization environment	Ground
12. Choice of Resist coating method	X-ray resist
13. Choice of Resist coating environment	Ground
14. Choice of Imprinting technique	Soft x-ray
15. Choice of Imprinting environment	Ground
16. Choice of mask type	X-ray lithographic
17. Choice of Mask fabrication environment	Space

Unknowns

1. Effects of zero-g on crystal growth.
2. Effects of various melt/solvent retention methods in zero-g.
3. In-orbit vibration levels, G-levels & isolation methods.
4. Electron beam mask cutting accuracy and vibration effects.
5. Quality of final SAW circuitry (accuracy, repeatability).
6. Effects of technique variations on cost and equipment.
7. Effects of electron beam writing duration/spacecraft operations interaction.

Figure I-3. Decision Areas and Unknowns

The unknowns listed in Figure I-3 are those which form the basis for the subsequent definition of experiment and test Work Elements in the R&D portion of the Work Breakdown Structure. Current ground-based experimentation on the full spectrum of crystal-growing techniques, supplemented by analysis of the Skylab and Apollo-Soyuz crystal-growing results, are expected to provide eventual answers to the unknowns listed for crystals. On the other hand, the unknowns related to in-orbit vibrations, which have implications broader than for imprinting Surface Acoustic Wave circuitry, are now known to be under investigation, and are likely to be the pacing item in the development of this product. Resolution of any such unknowns through current or other future programs are not accounted for here, but will, of course, influence the future application of this Study's findings.

Baseline process data defining key requirements for the selected process are shown in Section II.2.4 and II.2.5.

SECTION II

DEVELOPMENT PROGRAM

The framework upon which development tasks, schedules, costs, equipment and facility needs, etc. are constructed, is the Work Breakdown Structure (WBS). While relatively unfamiliar outside the Aerospace/Military communities, it is felt to provide sufficiently valuable insight to program planning to warrant its introduction into this commercial product study.

We have, however, deviated from the usual WBS content. The long development effort for products under study, the need for both Space and Ground Processing steps, the obvious comparisons between familiar ground processes and the "new" space-involving process led us to establish a WBS based on process steps, rather than on equipment. Thus subsequent analyses could easily compare value-added versus cost-added for any process step.

This section of the report details the WBS for the Surface Acoustic Wave device processing program and summarizes the Work Element Descriptions, Work Element Resource Requirements, and Resource Costs. Finally, it assembles the Development Schedule.

II.1 WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure against which the development and production tasks are organized is shown in Figure II-1 A&B. Figure II-1A depicts the configuration of the WBS at the top level, while II-1B delineates the detailed structure. The development effort which is documented in over 130 pages of Work Element Descriptions, Work Element Resource needs and Resource Costs, is summarized in Section II.2.

The technical and business assessment of the in-space Surface Acoustic Wave device processing opportunity requires that all elements of work required, from raw materials

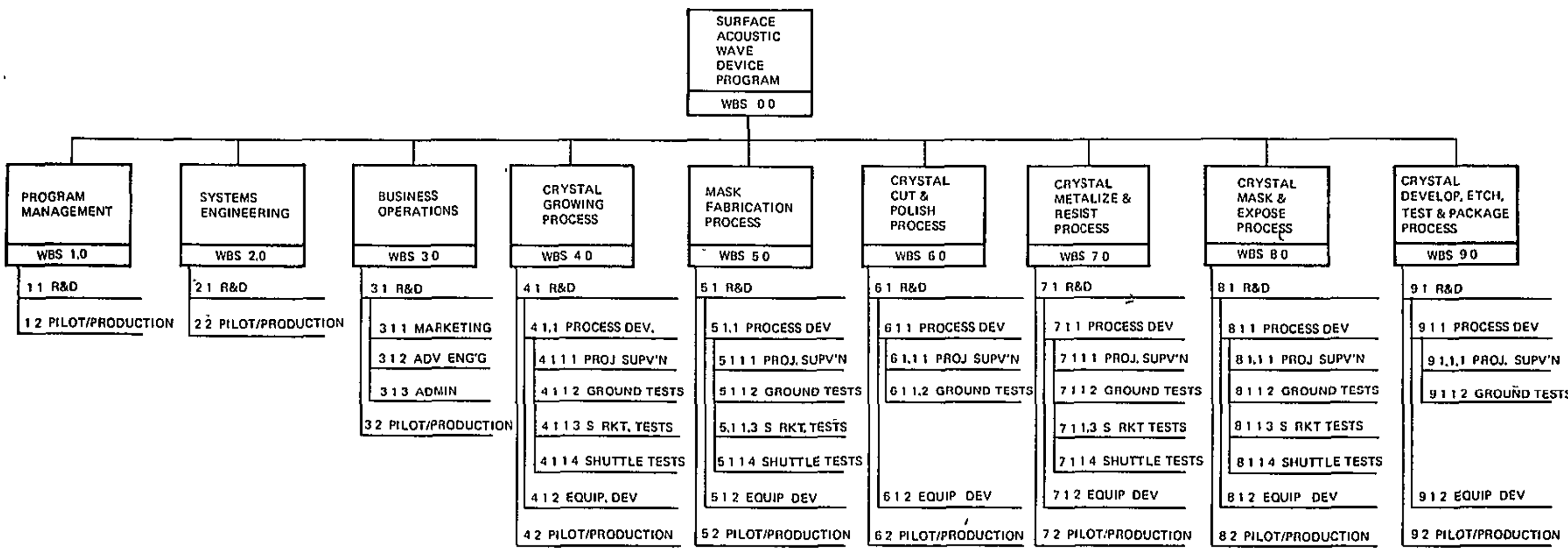


Figure II-1A. Surface Acoustic Wave Device Work Breakdown Structure

- 1.0 Program Management
  - 1.1 Program Management - R&D
  - 1.2 Program Management - Pilot/Production
- 2.0 System Engineering
  - 2.1 System Engineering - R&D
  - 2.2 System Engineering - Pilot/Production
- 3.0 Business Operations
  - 3.1 Business Operations - R&D
  - 3.2 Business Operations - Pilot/Production
- 4.0 Crystal Growing Process Step (Space)
  - 4.1 Crystal Growing Process Step - R&D
    - 4.1.1 Process Development
      - 4.1.1.1 Project Supervision
      - 4.1.1.2 Ground Lab Tests
        - 4.1.1.2.1 Crystal Growing Techniques 1-G (Test 2-A)
      - 4.1.1.3 Sounding Rocket Test (Eliminated)
      - 4.1.1.4 Shuttle Tests or Spacecraft Tests - Zero-G
        - 4.1.1.4.1 Crystal Growing Techniques - Zero-G
    - 4.1.2 Equipment Development and Test
  - 4.2 Crystal Growing Process Step - Pilot/Production
- 5.0 Mask Fabrication Process Step (Space)
  - 5.1 Mask Fabrication Process Step - R&D
    - 5.1.1 Process Development
      - 5.1.1.1 Project Supervision
      - 5.1.1.2 Ground Lab Tests
        - 5.1.1.2.1 Electron Beam Resolution for Mask Cutting (Test 1)
        - 5.1.1.2.2 Vibration Analysis (Test 6-A)
      - 5.1.1.3 Sounding Rocket Tests (Eliminated)
      - 5.1.1.4 Spacecraft/Shuttle Tests
        - 5.1.1.4.1 Mask Fabrication Tests - Zero-G (Test 6-B)
    - 5.1.2 Equipment Development and Test
  - 5.2 Mask Fabrication Process Step - Pilot/Production
- 6.0 Crystal Cut & Polish Process Step (Ground)
  - 6.1 Crystal Cut & Polish Process Step - R&D
    - 6.1.1 Process Development
      - 6.1.1.1 Project Supervision
      - 6.1.1.2 Ground Lab Tests
        - 6.1.1.2.1 Basic Phenomenology - Crystal Cutting & Polishing
        - 6.1.1.2.2 Process Development
        - 6.1.1.2.3 Prototype Process
  - 6.2 Crystal Cut & Polish Process - Pilot/Production
- 7.0 Crystal Clean, Metallize & Resist Process Step (Ground)
  - 7.1 Crystal Clean, Metallize & Reist Process - R&D
    - 7.1.1 Process Development
      - 7.1.1.1 Project Supervision
      - 7.1.1.2 Ground Lab Tests
        - 7.1.1.2.1 Ultra-Cleaning Tests (Test 3)
        - 7.1.1.2.2 Metallization Tests (Test 4)
        - 7.1.1.2.3 Resist Tests (Test 5)
    - 7.1.2 Equipment Development and Test
  - 7.2 Crystal Clean, Metallize & Resist Process - Pilot/Production
- 8.0 Crystal Mask & Expose Process Step (Ground)
  - 8.1 Crystal Mask & Expose Process Step - R&D
    - 8.1.1 Process Development
      - 8.1.1.1 Project Supervision
      - 8.1.1.2 Ground Lab Tests
        - 8.1.1.2.1 Vibration Effects on X-Ray Exposure (Test 7)
    - 8.1.2 Equipment Development & Test
  - 8.2 Crystal Mask & Expose Process Step - Pilot/Production
- 9.0 Crystal Develop, Etch, Clean & Test Process Step (Ground)
  - 9.1 Crystal Develop, Etch, Clean & Test Process Step - R&D
    - 9.1.1 Process Development
      - 9.1.1.1 Project Supervision
      - 9.1.1.2 Ground Lab Tests
        - 9.1.1.2.1 Basic Phenomenology
        - 9.1.1.2.2 Process Development
  - 9.2 Crystal Develop, Etch, Clean & Test Process Step - Pilot/Production

Figure II-1B. Surface Acoustic Wave Device Work Breakdown Structure

to finished product be examined, costed, and assessed. The main process steps provide a suitable framework for collecting tasks and costs over that sequence of events, and this approach tends to assure that no major business costs are overlooked. Six major process steps are defined for Surface Acoustic Wave device processing:

Crystal Growing	(WBS 4.0)
Mask Fabrication	(WBS 5.0)
Crystal Cut and Polish	(WBS 6.0)
Crystal Metallization & Resist Coating	(WBS 7.0)
Crystal Mask & Exposure	(WBS 8.0)
Crystal Develop, Etch, Test, & Package	(WBS 9.0)

To the above six elements, work elements for integrating and planning the development and pilot/production program are added as follows:

Program Management	(WBS 1.0)
System Engineering	(WBS 2.0)
Business Operations	(WBS 3.0)

Each major WBS element is divided into R&D and Pilot/Production phases, with the R&D phase ending at completion of a prototype capability. Work and cost summaries can thus be obtained either for a process step or for a particular phase. The ability to summarize a process step facilitates comparison of the cost of a process relative to others, assessment of alternatives (e.g., ground - versus space - ultra-cleaning of substrate surface), the examination of value added in each process step and examination of the option to sell as a product, the output of a particular process step.

Within each process, work is subdivided as to whether it is Process Development (requirements, system design, subsystem and system tests) or Equipment Development (component design and test based on process requirements). Hardware breakdown as used in aerospace Work Breakdown Structure occurs at lower levels of the Equipment Development branch.

II.2 WORK ELEMENTS (WORK TO BE DONE)

The development of a ground/space process for fabrication of Surface Acoustic Wave devices capable of operating at 30 GHz, such as that pictured in Figure II-2, can be summarized into the following summary work elements:

1.0 Program Management

2.0 System Engineering

3.0 Business Operations

4.0 Crystal Growing Process Step (in-space)

5.0 Mask Fabrication Process Step (in-space and ground)

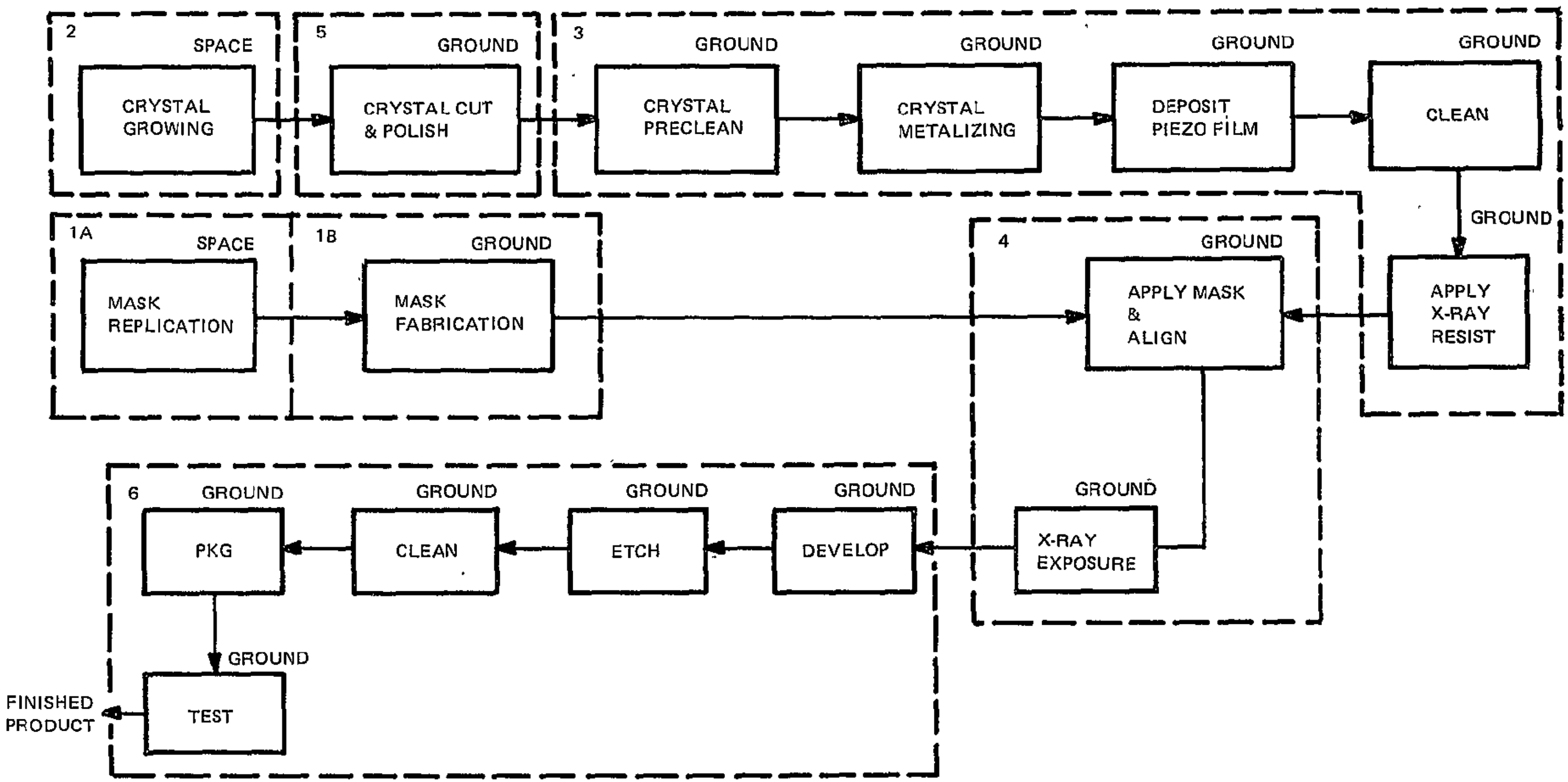
6.0 Crystal Cost & Polish Process Step (ground)

7.0 Crystal Clean, Metallize & Resist Process Step (ground)

8.0 Crystal Mask & Expose Process Step (ground)

9.0 Crystal Develop. Etch, Clean & Test Process Step (ground)

These elements apply to both the development (R&D) phase and pilot/production phase. The R&D effort is largely concentrated in the in-space elements 4.0, and 5.0, and this development plan accordingly emphasizes those areas of work. A description of the work to be done in each element is given in the following paragraphs. The development program includes a series of major experiments and tests as shown in Figure II-3A. The Shuttle tests are summarized in Figure II-3B.



EQUIPMENT/FACILITIES

1A. SPACE MASK FABRICATION FACILITY
1B. GROUND MASK REPLICATION FACILITY
2. SPACE CRYSTAL GROWING FACILITY
3. GROUND CRYSTAL CLEAN, METALIZE, FILM DEPOSIT, CLEAN, RESIST APPLICATION FACILITY
4. GROUND MASKING & X-RAY EXPOSURE FACILITY
5. GROUND CRYSTAL CUT & POLISH FACILITY
6. GROUND DEVELOP. ETC, CLEAN, PACKAGE, TEST FACILITY

Figure II-2. Surface Acoustic Wave Device Manufacturing Process Steps and Facilities

1.		Electron Beam Resolution For Mask Cutting	(Ground)	5.1.1.2.1
2.	A.	Crystal Growing Method Evaluation And Development	(Ground)	4.1.1.2.1
	B.	Crystal Growing Method Evaluation And Development	(Shuttle)	4.1.1.4.1, 4.1.2, 4.2
3.		Ultra-cleaning Methods	(Ground)	7.1.1.2.1, 7.1.2, 7.2
4.		Metallization Methods	(Ground)	7.1.1.2.2, 7.1.2, 7.2
5.		Resist Coating Application Methods	(Ground)	7.1.1.2.3, 7.1.2, 7.2
6.	A.	Vibration Effects on Electrode Patterns Formation	(Ground)	5.1.1.2.2
	B.	Mask Fabrication Method Evaluation and Development	(Shuttle)	5.1.1.4.1, 5.1.2, 5.2
7.	A.	Crystal Wafer Cut and Polish	(Ground)	6.1.1.2.1, 6.1.1.2.2
	B.	Vibration Effects on X-ray Lithography	(Ground)	8.1.1.2.1, 8.2
8.		Device Finishing	(Ground)	9.1.1.2.1, 9.1.1.2.2, 9.2

Figure II-3A. Surface Acoustic Wave Test Series

WBS NO	TESTS	EXPERIMENT NO.	POWER REQUIREMENT (KW)	EXPERIMENT WEIGHT (KG)	EXPERIMENT VOLUME (M^3)	FLIGHT DATE (YR)	TOTAL EXPERIMENT DURATION (HRS)	FLIGHT CREW SUPPORT REQUIREMENT (YRS/MO)	FLIGHT VEHICLE	DATA TRANSMISSION REQUIREMENTS	DATA PROCESSING REQUIREMENTS	ENERGY REQUIREMENTS (KWH)
4 1.1.4.1	Crystal growing	2	5	100	1.5	80	80-120 hrs	14 hrs.	SL-1	TBD	TBD	600
4 1 1.4.1	Crystal growing	2	5	100	1 5	81	80 120 hrs.	14 hrs.	SL-2	TBD	TBD	600
4.1.1.4.1	Crystal growing	2	5	100	1.5	82	80-120- hrs.	14 hrs.	SL-3	TBD	TBD	600
5.1.1.4 1	Electron Beam Mask Cutting	6	4	545	0 6	80	156 hrs.	14 hrs.	SL-1	NONE	NONE	600
5.1 1 4.1	Electron Beam Mask Cutting	6	4	545	0 6	81	156 hrs.	14 hrs.	SL-2	NONE	NONE	600
5 1 1.4.1	Electron Beam Mask Cutting	6	4	545	0 6	82	156 hrs.	14 hrs.	SL-3	NONE	NONE	600

Figure II-3B. Surface Acoustic Wave Device Processing Flight Test Requirements for R&D

II.2.1 PROGRAM MANAGEMENT (WBS 1.0)

Program Management in the R&D phase will include the definition of development tasks and schedules, arranging for and controlling the resources needed, and maintaining a management liaison with the parties involved. These parties will include the S.A.W. devices research laboratory, product manufacturer, space systems contractor, NASA contractors. While each development area (process step) will include project supervision of that work, Program Management will provide for the overall management and integration of all aspects of the program. Reports, presentations, special documents and plans are also included in Program Management. When the production phase is instituted, Program Management will be phased out and handled by administrative and production control functions of the business.

Some project engineering services will be required to handle shuttle services and interfaces.

II.2.2 SYSTEM ENGINEERING (WBS 2.0)

In the R&D phase, System Engineering will be required to establish requirements and specifications for the overall ground-space-ground process to be designed, and to integrate or conduct tests of overall processes. As development tests eliminate the present unknowns and technology gaps, System Engineering will convert these findings to a specific prototype system design (ground-space) and ultimately to a pilot/production facility design as portrayed in Figure II-4. In commercial terms, this is a combined plant engineering and product engineering activity, with the added dimensions of space vehicle/payload interfacing and orbital operations requirements. The output of the R&D System Engineering effort will be overall process and materials specifications and process equipment design requirements. In the production phase, System Engineering phases out and is replaced by Advanced Engineering.

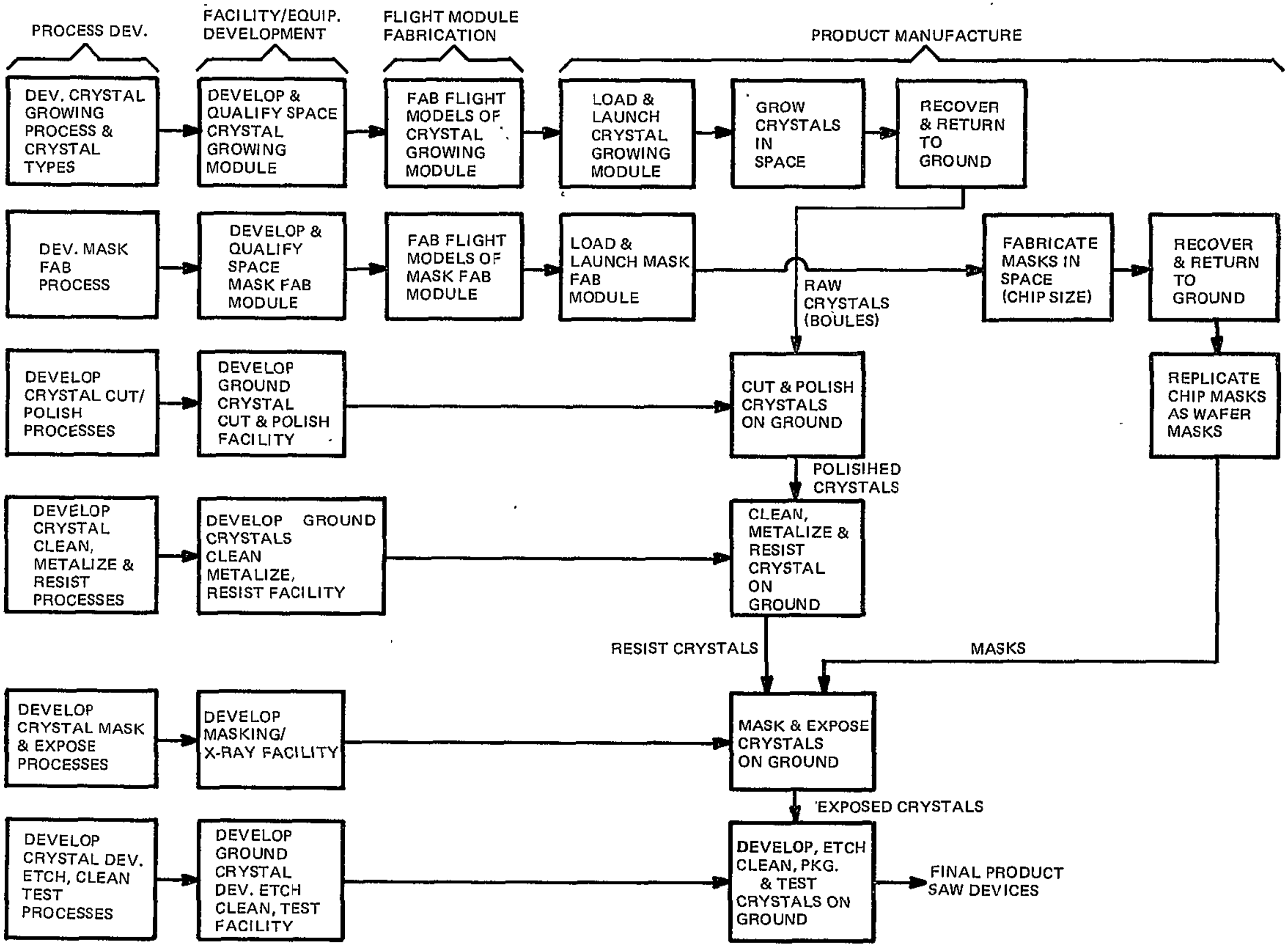


Figure II-4. Surface Acoustic Wave Devices Production-Development and Mission Profile

II.2.3 BUSINESS OPERATIONS (WBS 3.0)

Business Operations in the R&D phase will be concerned with business preparations in anticipation of a successful development effort and initiation of production. Business planning must be done continuously as a basis for investment decisions as R&D results are obtained. Three areas of business operations are described as follows.

Marketing (WBS 3.1.1, 3.2.1)

Development program initiation is necessarily based on very early estimates of business viability and financial returns. During the R&D activity, Marketing must continuously analyze the potential market, market share, anticipated orders, product offerings, gross margins, product costs, profits, etc., in order to confirm or modify earlier plans. As the time of pilot production approaches, Marketing will prepare sales literature, preliminary catalog data, and price data as the basis for customer count acts. The product distribution system will be designed and an appropriate sales organization will be initiated. Demonstrations of product characteristics and performance will be conducted using samples from early tests, and prototype/pilot runs to convince customers of product advantages and to establish a preliminary/seller-purchaser understanding. Introduction of S.A.W. devices at operating frequencies approaching 30 GHz implies an electronics industry expansion into this area, and introduction of products which require 30 GHz SAW devices. Advance orders will be solicited as early as possible in the R&D phase to reduce the risk associated with a commitment to build production facilities. When the production phase begins, Marketing will conduct routine order processing, cataloging, product service, product planning, and sales engineering activities as well as future market/business planning.

Advanced Engineering (WBS 3.1.2, 3.2.2)

Advanced Engineering will be relatively quiescent during the R&D phase, since the R&D System Engineering and R&D Experiment and Test tasks will be accomplishing that function. A limited amount of second generation technical investigation will be done to explore opportunities which lie beyond the scope of the R&D effort. These

findings may have an effect on the direction of the R&D effort. When the production phase begins, Advanced Engineering work will increase to develop improvements in the pilot/production design and to introduce new processes, facilities, and products as suggested by Marketing plans.

Financial, Legal & Relations Support (WBS 3.1.3, 3.2.3)
In the R&D phase, the Finance, Legal, & Relations functions will participate with Marketing in the preparation and critique of business plans, and recommending of steps to be taken by management to prepare for production. The timing and amount of investment will be critical, with pressures to move quickly to establish a market position, and concurrent pressures to postpone action, to reduce financial risk. Relations will be concerned with staffing of R&D positions and planning staff. Legal will address the contract/subcontract terms anticipated for production and the insurance/indemnity/warranty provisions that are planned to be used. This work will include establishing of the terms for using NASA shuttle services, and the associated manufacturer/NASA liabilities.

II.2.4 CRYSTAL GROWING PROCESS STEP (IN-SPACE) (WBS 4.0)

SAW devices operating at 30 GHz require that crystals of unusually high quality (flatness, homogeneity, freedom from inclusions, strains, and defective growth patterns) be used. An R&D effort is required to examine the basic phenomenology of candidate crystal materials (lithium niobate, sapphire, spinel, etc.) and to develop a process for growing such crystals with high perfection. It is possible that by the mid-80's, an outside commercial source for suitable crystals will be established, and that this process step will not be necessary. However, no outside source is foreseen at this time, and so the crystal growing step is necessarily addressed. Apart from selecting the crystal materials, research and development is required to establish a prototype process for growing high perfection crystals, which we believe will be best accomplished in a zero-G environment, with a throughput (boule size, shape, crystal structure, pulling rate, growing technique, etc.) which is compatible with later production requirements.

Ground lab, sounding rocket and shuttle/spacelab experiments, such as those listed in Figure II-5, will be required to test design approaches, and to develop specific equipments for in-space crystal growth (crucible, furnace, solvent/melt retention, crystal seed and retrieval, power interfaces, etc.). Figures II-6 and II-7 provide representative Work Element Descriptions, Resource Requirements and Resource Costs of typical testing required, While Figure II-8 lists baseline data for both a typical Shuttle experiment and the production operation. Figure II-9 represents a crystal-growing facility for advanced experiments leading to scale-up to production. Its planform dimensions remain constant, but its height can be increased as the crystal-growing technique develops. In its earliest version this configuration is only 56cm. in height, and, thus is limited to growing crystals 11" long. By replacing the outer structure and extending the crystal-holder spindle and its housing to a height of 112cm, the facility can accommodate crystal growth to the production goal of 59 cm. (22 inches) in length.

Figures II-10 and II-11 typify some of the equipment likely to be useful in early experiments to perform comparative evaluations of the various techniques for growing Lithium Niobate.

A summary of our current view on those equipments most logical for a continuing program to develop and produce crystals space processed Surface Acoustic Wave components is given in Figure II-12, which lists the development status of key items, and the number needed.

Few special requirements of crystal-growing are of great concern, and Figure II-13 summarizes them.

A necessary adjunct to the development of the crystal growing facility is the development of an in-space power source of high (~ 30 KW) continuous power capacity and low cost per KWH. This effort is not included in the tasks of this development plan, except as needed to arrive at an operational cost per KWH for economic feasibility analyses.

FACILITY	EXPERIMENTS AND VERIFICATION TESTS	OBJECTIVES	EXPERIMENT AND TEST REQUIREMENTS (SUMMARY)
GROUND LAB	Experiments (extension of present ground) and Skylab techniques) of flux growth, Czochralski. Other growth of lithium niobate, sapphire, spinel, lithium tantalate, bismuth germanate for selection of method and materials (limits of size, purity, freedom from dislocations, also surface plane alignment).	Best for: largest size, highest quality, freedom from dislocations, surface principal plane alignment, cost.	Standard Ground Lab with standard flux growth, Czochralski, other crystal growing equipment, candidate crystal materials; rigorous thermal, vibration, atmosphere control and instrumentation; photographic measurement apparatus ~ 2 days per run. Manual control.
	Tests to develop space mask fabrication method	Vibration levels in spacecraft Isolation, fabrication methods to achieve 200 A° lines and spaces	Ground lab mask fabrication apparatus Candidate vibration isolators Mask samples Vibration instrumentation Automated One day per run
	Evaluate process (including vibration isolation)	Vibration levels in spacecraft. Isolation, fabrication methods to achieve 200 A° lines and spaces	Ground lab with soft x-ray lithography system, vibration isolation, vibration measuring instrumentation Sample masks, resist-coated substrates Automated ~ minute per run
ENGINEERING LAB	Tests and demonstration of prototype equipment, system, and products	Timing, steps capable of/feasible for, automation	Facility tests and demonstration First, major equipments; later, total system Process instrumentation, sample raw materials. First, manual, later automated with manual control Up to 2 days per run. Standard S A W. Ground Test Lab. Electronic equipment test equipment for S A.W performance
DROP TOWER	Tests to establish procedure, performance, contamination of space methods (if required) Comparison of sputtering vs vapor deposition	Sputtering in Zero "G" hard vacuum technology, cost, weight, quality of results Vapor deposition in Zero "G", hard vacuum technology, cost, weight, quality of results	Drop Tower tests Sputtering and vapor deposition apparatus Environment instrumentation, photography Rigorous contamination control Sample crystal salbs, metallization chamber Automated 4 seconds per run Recording and or telemetry of data Recovery of sample slabs, metallization chamber, photography Tests required only if preferred in-space metallization is adopted mode
KC 135	Tests to establish procedure, performance, contamination effects of space methods (if required) Comparison of Ion beam scrubbing vs. back sputtering	Ion beam scrubbing in hard vacuum – cost, weight, quality of results Back sputtering in Zero "G" hard vacuum technology, cost, weight, quality of results	Zero "G" aircraft tests Ion beam scrubbing and back sputtering apparatus Environment instrumentation, photography Rigorous contamination control Sample crystal slabs Cleaning chamber Automated 20 sec. per run Recording and/or telemetry of data. Recovery of sample slabs cleaning chamber, photography. Tests required only if preferred in space ultra-cleaning is adopted mode
	Tests to establish procedure, performance, contamination of space methods (if required) Comparison of sputtering vs vapor deposition,	Sputtering in Zero "G" hard vacuum technology, cost, weight, quality of results Vapor deposition, in Zero "G", hard vacuum technology, cost, weight quality of results	Zero "G" Aircraft tests Sputtering and vapor deposition apparatus Environment instrumentation, photography Rigorous contamination control Sample crystal slabs, metallization chamber Automated 20 seconds per run Recording and or telemetry of data Recovery of sample slabs, metallization chamber, photography Tests required only if preferred in space metallization is adopted mode.
	Tests to evaluate (possibly modify) "spinner" method for procedure, performance, contamination effects	Method for Zero "G", technology cost weight, quality of results	Zero "G" aircraft tests "Spinner" and modified "spinner" apparatus Environment instrumentation Photography Rigorous contamination control Sample crystal slabs. Resist application chamber Automated.
	Test to evaluate (possibly modify) crystal melt/flux retention method for procedure, performance, "g" effects.	Method for Zero "G", technology cost, weight, quality of results.	Sounding Rocket tests. Non-contact and modified crucible apparatus. Environment instrumentation. Photography. Sample crystal materials. Automated. 10 min. per run. Recording and/or telemetry of data. Recovery of samples. Chamber, photography.

Figure II-5. Experiments to Verify Selected Approach for Fabrication of Surface Acoustic Wave Components

TASK DESCRIPTION

TASK TITLE: Crystal Growing Techniques 1-G (Test 2A)		
WBS NO. 4.1.1.2.1	PREPARED BY SWT	DATE 3/6/75

1. REQUIRED OUTPUT:

Report: Crystal Growing Methods
Poling Methods
Candidate Materials, Characteristics and Sources
Orientation, Cutting, Polishing, Cleaning

2. REQUIRED INPUT:

Available Commercial Crystals
Results of crystal growing studies from literature

3. DESCRIPTION OF EFFORT:

Evaluate materials, such as lithium niobate, sapphire, spinel, lithium tantalate, bismuth germanate, quartz, diamond.

Test selected crystals for necessary properties.
Set up crystal growing apparatus in ground lab.
Grow crystals of centimeter size, for evaluation by x-ray diffraction tests, electron microscope tests, and high frequency SAW tests.
Evaluate crystal limitations when grown in 1-G environment.

4. PERFORMANCE PERIOD:

1975 - 1977

PERFORMANCE RESPONSIBILITY: Research Lab	APPROVAL:

NOTE CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED

Figure II-6. Task Description

TASK RESOURCE REQUIREMENTS

TASK TITLE		
Crystal Growing Techniques 1-G (Test 2A)		
WBS NO. 4.1.1.2.1	PREPARED BY SWT	DATE 3/6/75

1. PURCHASED MATERIALS: (INCLUDE ASSUMPTIONS)

- Commercially available SAW crystals
- Raw materials for crystal growing and processing

2. PURCHASED SERVICES: (INCLUDE ASSUMPTIONS)

- Crystal cutting, polishing, poling, cleaning when appropriate
- Computer services

3. EQUIPMENT: (INCLUDE ASSUMPTIONS)

- Develop crystal growing apparatus
- Purchase orientation and cutting equipment
- Develop poling equipment

4. FACILITIES: (INCLUDE ASSUMPTIONS)

Assume standard laboratory facilities:

- Furnaces
- X-ray diffraction equipment
- Scanning electron microscope with microprobe
- Microwave facilities for SAW device testing

APPROVAL:

NOTE: CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED.

BUS-3

Figure II-6. (Cont.) Task Resource Requirements

WORK ELEMENT COSTS							
WORK ELEMENT NO. 4.1.1.2.1	WORK ELEMENT TITLE Crystal Growing Techniques 1-G (Test 2A)						
1 ACT. NO.	2 ACTIVITY	3 LABOR COST	4 PURCHASED MATERIALS COST	5 SERVICES COST	6 EQUIPMENT COST	7 FACILITIES COST	8 TOTAL COST
	1. Evaluate materials, test for crystal properties, grow crystals in 1-G.	$150K	$35K	$10K	$15K	None	$210K
	TOTALS	$150K	$35K	$10K	$15K	–	$210K

Figure II-6. (Cont.) Work Element Costs

TASK DESCRIPTION

TASK TITLE: Crystal Growing Shuttle Tests Zero-G

WBS NO. 4.1.1.4.1	PREPARED BY SWT	DATE 3-5-75

1. REQUIRED OUTPUT:

Report:
Methods for growing crystals under Zero-G.
Crystals for use in R&D tests of electron beam, lithography and X-ray replication of SAW devices.

2. REQUIRED INPUT:

Results of Crystal growing investigation under Task 4.1.1.2.1.

3. DESCRIPTION OF EFFORT:

With selected materials and growth techniques from Task 4.1.1.2.1, develop R&D equipment for crystal growing in orbit.

Evaluate crystals for high frequency SAW use, and correlate the effects of the space environment on presence of crystal defects.

4. PERFORMANCE PERIOD:
1977 - 1982

PERFORMANCE RESPONSIBILITY: Research Lab	APPROVAL:

NOTE: CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED

BUS-1

Figure II-7. Task Description

TASK RESOURCE REQUIREMENTS		
TASK TITLE Crystal Growing, Shuttle Tests Zero-G		
WBS NO. 4.1.1.4.1	PREPARED BY SWT	DATE 3-5-75

1. PURCHASED MATERIALS: (INCLUDE ASSUMPTIONS)

Materials for crystal growing and processing.

2. PURCHASED SERVICES: (INCLUDE ASSUMPTIONS)

- Crystal cutting, polishing, poling, cleaning when appropriate.
- Computer services
- Shuttle launch and in-orbit services (NASA)

3. EQUIPMENT: (INCLUDE ASSUMPTIONS)

Develop crystal growing equipment for space R&D.

4. FACILITIES: (INCLUDE ASSUMPTIONS)

- Assume standard lab facilities (as in Task 4.1.1.2.1)
- Equipment developed and purchased for Task 4.1.1.2.1

	APPROVAL:

NOTE: CONTINUE NUMBERED ITEMS ON SEPARATE SHEET AS REQUIRED.

BUS-3

Figure II-7. (Cont.) Task Resource Requirements

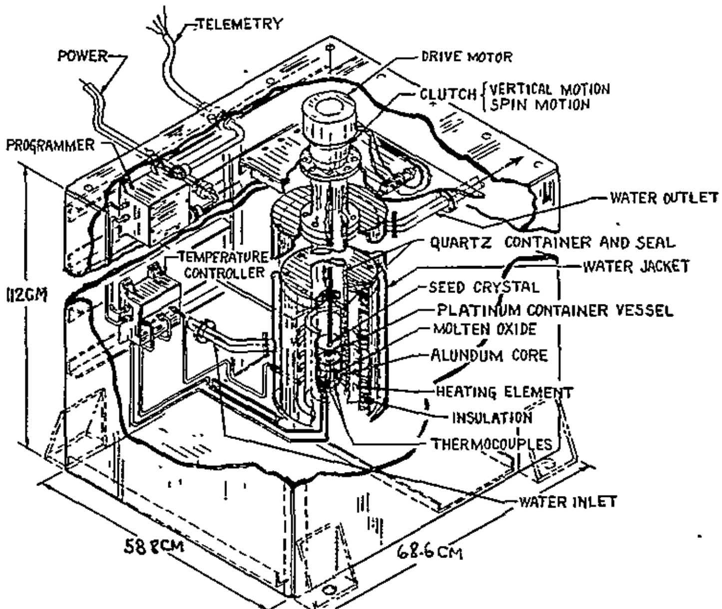
WORK ELEMENT COSTS								Zero G
WORK ELEMENT NO.		WORK ELEMENT TITLE Crystal Growing Shuttle Tests						
1 ACT. NO.	2 ACTIVITY	3 LABOR COST	4 PURCHASED MATERIALS COST	5 SERVICES COST	6 EQUIPMENT COST	7 FACILITIES COST	8 TOTAL COST	
1.	Crystal growth technology, materials testing & data analysis (Research Lab)	$150K	$5K	$10K	$25K	None	$190K	
2.	Flight No. 1 Payload design, lab, test, flight support, data analysis	352K	22K	-	20K	-	394K	
	NASA Space Changes	-	-	860K	-	-	860K	
3.	Flight No. 2	97K	5K	-	2K	-	104K	
	NASA Space Charges	-	-	860K	-	-	860K	
4.	Flight No. 3	97K	5K	-	2K	-	104K	
	NASA Space Charges	-	-	860K	-	-	860K	
	TOTALS	696K	37K	2590K	49K	-	3372K	

Figure II-7. (Cont.) Work Element Costs

Surface Acoustic Wave Device Crystal Growing Process Baseline (Modified Flux and Czochralski)		
Item	Experiments	Production
Crystal Material	Lithium Niobate	Lithium Niobate
Solvent Material (If Req'd)	Lithium Silicate	Lithium Silicate
Seed Insertion Method	Mechanical Sting	Mechanical Sting
Growth Rate	Up to .5cm/hr	2.5cm/hr (5 processors)
Charge Size	Up to 12KG	Up to 60KG (5 processors)
Boule Size	Up to 4cm diam. x 22cm	Min. 4cm diam. x 22cm
Temperature of Solution/Melt	1000 to 1300^{o}C	1000 to 1300^{o}C
Environment During Growth	Argon	Argon
Cooling Rate (During Growth)	0 to 1^{o}C/hr	0 to 1^{o}C/hr
Cooling Method	Controlled Radiation	Controlled Radiation
Growth Time (1 boule)	44 to 144 hours	<44 hours
Heating Power	5KW	30KW
Input Power	7KW	45KW
Product Recovery	Manual	Manual
Total Processing Time	48 to 150 hours	Max. 44 hours
Vehicle Acceleration (Allowable During Growth)	10^{-4}g	10^{-4}g

Figure II-8. Crystal Growing Process Baseline

The objective of the crystal growing process step is to achieve an in-space facility capable of full scale production throughput (in the order of 100 Kg/yr of 4 Cm diameter crystal boules. The concept used is that of a crystal-growth facility in Space-lab configuration, supported by a spacecraft power station (e.g. nuclear); transported to earth orbit and logistically supported by Space Shuttle. Successful accomplishment of this objective would make available a crystal product which would be not only usable for S.A.W. devices, but also marketable as a bulk crystal product for other applications.



CRYSTAL GROWING

Crystal Growing Facility Weight and Power

	Experimental Unit	Production Unit
Structure	100 lb.	200 lb.
Process Controller	5	10
Temperature Controller	5	10
Drive Motor & Clutch	15	30
Quartz Container	15	30
Heating Unit	5	10
Platinum Crucible	10	20
Solvent (If used)	5	10
Wiring, Ducting, Coolant, etc.	40	80
	91KG (200 lb.)	182KG (400 lb.) x6 for Production Level
		1092KG
Power	5KW Avg.	25KW Avg.

Figure II-9. Crystal Growing Facility

EQUIPMENT NAME Feed and Crystal Holder (F11E)	DATE 1/6/75

1. AVAILABILITY STATUS:

- [X] NEW, REQUIRES / YEARS TO DEVELOP
- [ ] MODIFICATION OF AVAILABLE EQUIP; COMPANY
- [ ] PRESENTLY AVAILABLE; COMPANY
- [ ] SPACE QUALIFIED; PROGRAM
- [ ] OTHER

2. EXPERIMENTS ACCOMMODATED: (EXPERIMENT NAME OR TYPE)

- Crystal Growth $\left\{\begin{array}{l}\text{Czochralski}\\\text{Flux}\end{array}\right.$
- Metallurgical Processes

3. DESCRIPTION OF EQUIPMENT OPERATION (MAJOR FUNCTIONS)

- To Hold and Manipulate (Rotate, Translate in one Dimension) a Specimen for molten zone crystal growth.
- Adjustable to permit specimen alignment

4. EQUIPMENT PHYSICAL DESCRIPTION (SKETCH, DIMENSIONS, VOLUME)

No. Req'd = 1
.15 m x .91 m x .15 m = $0.2m^3$
15.9 kg.

5. EQUIPMENT PERFORMANCE PARAMETERS (E.G., FLOW RATE, ENERGY OUTPUT, MAX TEMP., ETC)

Pulling Rate = .05 cm/hr (variable)
Rotation Rate = 1 RPM (variable)

With Specimens up to 50 cm^3

Figure II-10. Equipment - Feed and Crystal Holder (F11E)

EQUIPMENT NAME Feed and Crystal Holder (F11E)	DATE 1/6/75

6. INSTRUMENTATION: (E.G., THERMOCOUPLES, GAUGES, ETC, LOCAL & REMOTE)

- Rotational and translational speed measurement

7. SUPPORT SERVICES REQUIRED: (E.G., POWER, GASSES, VACUUM, COOLANT, OPERATOR ATTENTION)

- Power $\begin{cases} \text{Peak - 100W} \\ \text{Sustained - 25W} \end{cases}$
- Display and control for operator at crystal growing facility or in payload station.

8. EXTERNAL ENVIRONMENT REQUIRED: (E.G., ATMOSPHERE, VIBRATION LEVEL, ETC)

None

9. EXTERNAL ENVIRONMENT PRODUCED: (E.G., EMI, HEAT, CONTAMINATION, ETC)

Heat - 25W
EMI - Mainly conducted broadband from electrical motor. Filter will handle

10. SAFETY CONSIDERATIONS: (EQUIPMENT, OPERATORS, ETC)

Electrical grounding and overload circuit breakers

11. WASTES & PRODUCTS PRODUCED

Heat - 25W

Figure II-10. Equipment - Feed and Crystal Holder (F11E) (Cont'd.)

EQUIPMENT NAME	DATE
Feed and Crystal Holder (F11E)	1/6/75

12. DATA INPUT/OUTPUT REQUIREMENTS (AS EXTRACTED FROM ITEM 13)

20 BPS

13. FUNCTIONAL FLOW DIAGRAM (INCLUDE & NOTE AUTOMATED FUNCTIONS, DATA FLOW, CONTROL RANGES & LIMITS, ETC)

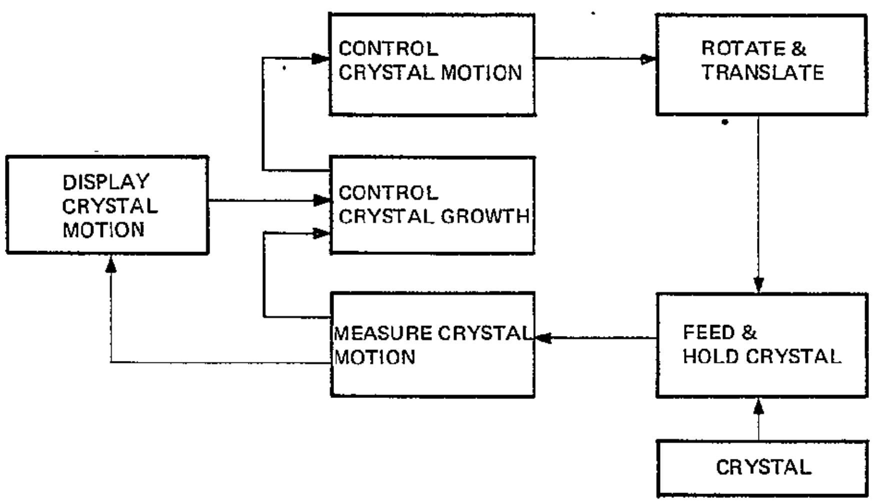


Figure II-10. Equipment – Feed and Crystal Holder (F11E) (Cont'd.)

EQUIPMENT NAME Hot Wall Furnace - 1800°C (F 2E)	DATE 1/3/75

1. AVAILABILITY STATUS:

- [x] NEW, REQUIRES YEARS TO DEVELOP ASTRD Industries, Inc.
- [ ] MODIFICATION OF AVAILABLE EQUIP; COMPANY
- [ ] PRESENTLY AVAILABLE; COMPANY
- [ ] SPACE QUALIFIED; PROGRAM
- [ ] OTHER

2. EXPERIMENTS ACCOMMODATED: (EXPERIMENT NAME OR TYPE)

- Crystal Growth - Early Flux Growth (Modified Bridgeman Method)
- Glass Preparation
- Metallurgical Processes

3. DESCRIPTION OF EQUIPMENT OPERATION (MAJOR FUNCTIONS)

- The unit is a general purpose hot wall heating device to provide the greatest degree of control over the hot zone temperature - either with respect to a uniform or flat profile or with respect to a specified gradient profile

4. EQUIPMENT PHYSICAL DESCRIPTION (SKETCH, DIMENSIONS, VOLUME)

- No. Req'd. - 1
- .3 m x .61m x .3m = .055 m^3
- wt - 45.4 kg.
- Vertical or horizontal mounting

5. EQUIPMENT PERFORMANCE PARAMETERS (E.G., FLOW RATE, ENERGY OUTPUT, MAX TEMP., ETC)

- Power { Peak - 9000 Watts (From power conditioner); Sustained - 5000 Watts Low volt/high amp.
- The hot zone temp. in furnace - 3000°C - (Outside temp. 45°C)
- Largest sample sizes up to 50 cm^3.

Figure II-11. Equipment - Hot Wall Furnace - 1800°C (F2E)

EQUIPMENT NAME	DATE
Hot Wall Furnace - 1800°C (F2E)	1/3/75

6. INSTRUMENTATION: (E.G., THERMOCOUPLES, GAUGES, ETC, LOCAL & REMOTE)

- A ceramic muffle tube for experiments in which oxides are to be heated.
- A viewing access to the heated speciman for pyrometer temp. monitoring and thermocouple access to the furnace interior and to the speciman is req'd.
- Cooling chamber assembly, gas control functions & gas flow metering
- Thermo couples

7. SUPPORT SERVICES REQUIRED: (E.G., POWER, GASSES, VACUUM, COOLANT, OPERATOR ATTENTION)

- At about 2×10^{-7} psi to avoid excess loss of heater material temp. must be limited to about 1600°C
- Vacuum flange opening up to 10 cm dia. which is consistent with high vacuum system
- Cooling req'd.
- Positive means of speciman support is req'd.

8. EXTERNAL ENVIRONMENT REQUIRED: (E.G., ATMOSPHERE, VIBRATION LEVEL, ETC)

- High vacuum or partial press. environment with the oxygen for reducing, or inert gas

9. EXTERNAL ENVIRONMENT PRODUCED: (E.G., EMI, HEAT, CONTAMINATION, ETC)

- Heat

10. SAFETY CONSIDERATIONS: (EQUIPMENT, OPERATORS, ETC)

- The choice of materials for the enclosure cavity should be such that it must withstand any temperature to which a hot molten sample may be raised.
- Some care will be required for fired tungsten heating elements during shipping, storage, and handling.

11. WASTES & PRODUCTS PRODUCED

- None

Figure II-11. Equipment - Hot Wall Furnace - 1800°C (F2E) (Cont'd.)

EQUIPMENT NAME Hot Wall Furnace - 1800°C (F2E)	DATE 1/3/75

12. DATA INPUT/OUTPUT REQUIREMENTS (AS EXTRACTED FROM ITEM 13)

Input ——→ Elec. power from power conditioner

Data Output - Temperature

13. FUNCTIONAL FLOW DIAGRAM (INCLUDE & NOTE AUTOMATED FUNCTIONS, DATA FLOW, CONTROL RANGES & LIMITS, ETC)

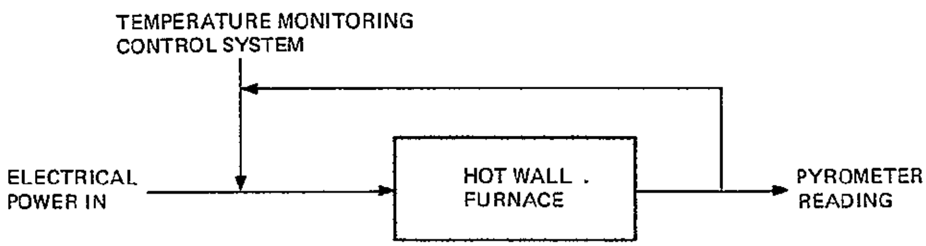


Figure II-11. Equipment - Hot Wall Furnace - 1800°C (F2E) (Cont'd.)

Surface Acoustic Wave Device Space Crystal Growing Facility Equipment Requirements

	Development Required	Quantity Required: Initial Studies (Gnd)	Proto (Space)	Pilot (Space)	Production (Space)
Crystal Feed and Holder	Yes	1	1	1	1
Hot Wall Furnace	Yes	1	1	1	?(6)
Modified Czochralski Apparatus	Yes	1	1	?	?(6)
Modified Flux Growth (Bridgeman) Apparatus	Yes	1	1	?	?(6)
Power Conditioner	Yes	0	1	1	2
Pyrometer	No	1	1	1	6
Melt/Solution Temperature Measurement	No	1	1	1	6
Inert Gas Supply and Control	No	1	1	1	1
Gas Evacuation and Control	No	0	1	1	1

Figure II-12. Equipment Development List

Requirement	Equipment or Operations Needed
Safety	
• Temperature	1300°C molten lithium niobate requires enclosure, fireproofing, possibly emergency quench.
• Electrical Power	Induction or contact heater is high power, require grounding, fusing, potting of connectors.
• Optical Radiation	Operator requires eye protection for comfortable viewing of specimen.
Wastes	
• Flux Growth Yields Solvent as Waste	Disposal requires receptacle for hot melt which will solidify.
• Heat	Facility thermal control must accommodate 1580 x 10^6 joules (production) 158 x 10^6 joules (experiment)

Figure II-13. Special Requirements for Growing S.A.W. Crystals

II. 2. 5 MASK FABRICATION PROCESS STEP (IN-SPACE) (WBS 5. 0)

A mask for use in imprinting (exposing) a 30 GHz circuit pattern on a 2mm x 2mm, SAW crystal must establish circuit paths (e. g. fingers) of 250 A° width, with spacing between fingers of 250 A° and a dimensional accuracy of ± 20-25 A°. This extreme accuracy cannot be achieved on earth (primarily due to seismic disturbances) and so an in-space process is necessary. The ground techniques presently being used for 3 to 4 GHz SAW devices must be refined and applied to the in-space environment to achieve the process. The R&D effort will require examination of the basic phenomenology and candidate techniques of mask cutting, using ground lab studies as shown in Figure II-14, and sounding rocket and Shuttle/Spacelab experiments. Vibration effects, vibration isolation methods and electron beam cutting techniques will be critical areas of this experimentation.

Mask cutting rates (on the order of one hour per 2 x 2mm circuit area) and crystal wafer throughput requirements of a facility such as that diagrammed in Figure II-15 will probably lead to the in-space cutting of relatively few 2 x 2mm masks of high re-usability (e.g. 500 to 1000 uses before discard) with subsequent replication into larger masks on the ground. These large masks would permit simultaneous exposure of many (100-200) individual circuits on a single crystal wafer of 3-4cm diameter. Mask cutting equipment must be developed, using existing laboratory scanning electron beam microscope designs and hardware such as the typical configuration pictured in Figure II-16 as a starting point, with attention to extension of EBM cathode life (presently 40-80 hours), computer control, vacuum provisions, and mask/wafer handling. The yield rate in mask fabrication will be important, owing to the very high estimated cost per mask. The prototype and the pilot/production facilities such as shown conceptually in Figure II-17 are envisioned as Shuttle/spacelab transported, with 7-day missions.

FACILITY	EXPERIMENTS AND VERIFICATION TESTS	OBJECTIVES	EXPERIMENT AND TEST EQUIPREMENTS (SUMMARY)
GROUND LAB	Experiments (extension of present ground) and Skylab techniques of flux growth, Czochralski Other growth of lithium niobate, sapphire, spinel, lithium tantalate bismuth germanate for selection of method and materials (limits of	Best for largest size, highest quality, freedom from dislocations, surface principal plane alignment, cost.	Standard Ground Lab with standard flux growth, Czochralski, other crystal growing equipment, candidate crystal materials, rigorous thermal, bivration, atmosphere control and instrumentation, photographic measurement apparatus ~ 2 days per run Manual control
	Experiments to measure vibration levels, effects on mask fidelity and accuracy.	**Vibration levels in spacecraft. Isolation, fabrication methods to achieve 200 A^{0} lines and spaces.**	**Ground Lab experiments. Vibration-measuring instrumentation. Automated. One day per run. Telemetry of data.**
	Tests to develop space mask fabrication method.	**Vibration levels in spacecraft. Isolation, fabrication methods to achieve 200 A^{0} lines and spaces.**	**Ground lab mask fabrication apparatus. Candidate vibration isolators. Mask samples. Vibration instrumentation. Automated. One day per run.**
	Evaluate process (including vibration isolation).	**Vibration levels in spacecraft. Isolation, fabrication methods to achieve 200 A^{0} lines and spaces.**	**Ground lab with sc'‹ x-ray lithography system, vibration isolation, vibration measuring instrumentation. Sample masks, resist-coated substrates. Automated ~ minute per run.**
DROP TOWER	Tests to establish procedure, performance, contami nation of space methods (if required) Comparison of sputtering vs vapor deposition	Sputtering in Zero "G" hard vacuum technology, cost, weight, quality of results Vapor deposition in Zero "G", hard vacuum technology, cost, weight, quality of results	Drop Tower tests Sputtering and vapor deposition apparatus Environment instrumentation, photography Rigorous contamination control. Sample crystal slabs, metallization chamber Automated, 4 seconds per run Recording and or telemetry of data Recovery of sample slabs, metallization chamber, photography. Tests required only if preferred in space metallization is adopted mode
KC 135	Tests to establish procedure, performance, contami nation effects of space methods (if required). Comparison of ion beam scrubbing vs back sputtering	Ion beam scrubbing in hard vacuum – cost, weight, quality of results Back sputtering in Zero "G" hard vacuum technology, cost, weight, quality of results	Zero "G" aircraft tests Ion beam scrubbing and back sputtering apparatus Environment instrumentation, photography Rigorous contamination control Sample crystal slabs Cleaning chamber Automated 20 sec per run, Recording and/or telemetry of data Recovery of sample slabs, cleaning chamber, photography. Tests required only if preferred in space ultra cleaning is adopted mode.
	Tests to establish procedure, performance, contami nation of space methods (if required) Comparison of sputtering vs vapor deposition.	Sputtering in Zero "G" hard vacuum technology, cost, weight, quality of results Vapor deposition in Zero "G", hard vacuum technology, cost, weight, quality of results	Zero "G" aircraft tests, Sputtering and vapor deposition apparatus Environment instrumentation, photography. Rigorous contamination control Sample crystal slabs, metallization chamber Automated 20 seconds per run, Recording and or telemetry of data Recovery of sample slabs, metallization chamber, photography. Tests required only if preferred in space metallization is adopted mode
	Tests to evaluate (possibly modify) "spinner" method for procedure, performance, contamination effects	Method for Zero "G", technology cost, weight, quality of results.	Zero "G" aircraft tests "Spinner" and modified "spinner" apparatus Environment instrumentation Photography. Rigorous contamination control Sample crystal slabs Resist application chamber. Automated. 20 sec per run Recording and/or telemetry of data Recovery of sample slabs, resist application chamber. Photography Tests required only if preferred in space resist coating is adopted mode
SOUNDING ROCKET	Tests to establish procedure, performance, contami nation effects of space methods (if required) Comparison of ion beam scrubbing vs back sputtering	Ion beam scrubbing in hard vacuum – cost, weight, quality of results Back sputtering in Zero "G" hard vacuum – technology, cost, weight, quality of results	Sounding Rocket tests Ion beam scrubbing and back sputtering apparatus. Environment instrumentation, photography. Rigorous contamination control Sample crystal slabs Cleaning chamber Automater, 10 min per run, Recording and/or telemetry of data Recovery of sample slabs, cleaning chamber, photography Tests required only if preferred in space ultra cleaning is adopted mode.
	Test to evaluate (possibly modify) crystal melt/flux retention method for procedure, performance, "g" effects	Method for Zero "G", technology cost, weight, quality of results	Sounding Rocket tests Non-contact and modified crucible apparatus Environment instrumentation. Photography Sample crystal materials Automated 10 min per run Recording and/or telemetry of data. Recovery of samples Chamber, photography

Figure II-14. Experiments to Verify Selected Approach for Fabrication of Surface Acoustic Wave Components

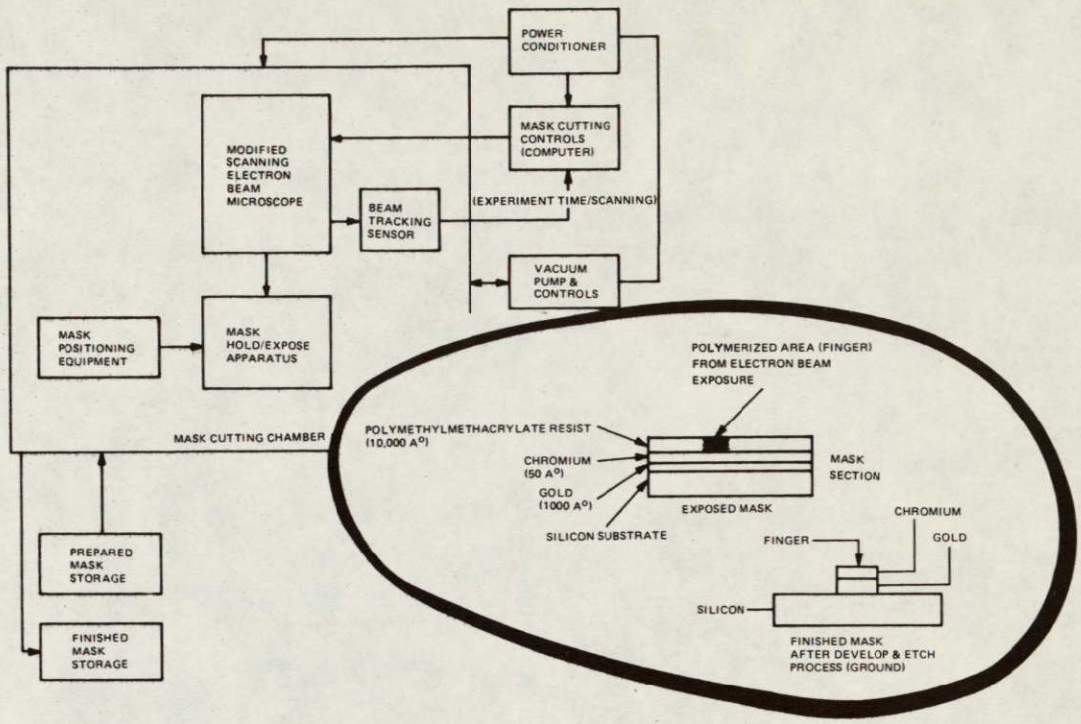


Figure II-15. In-Space Mask Fabrication Facility

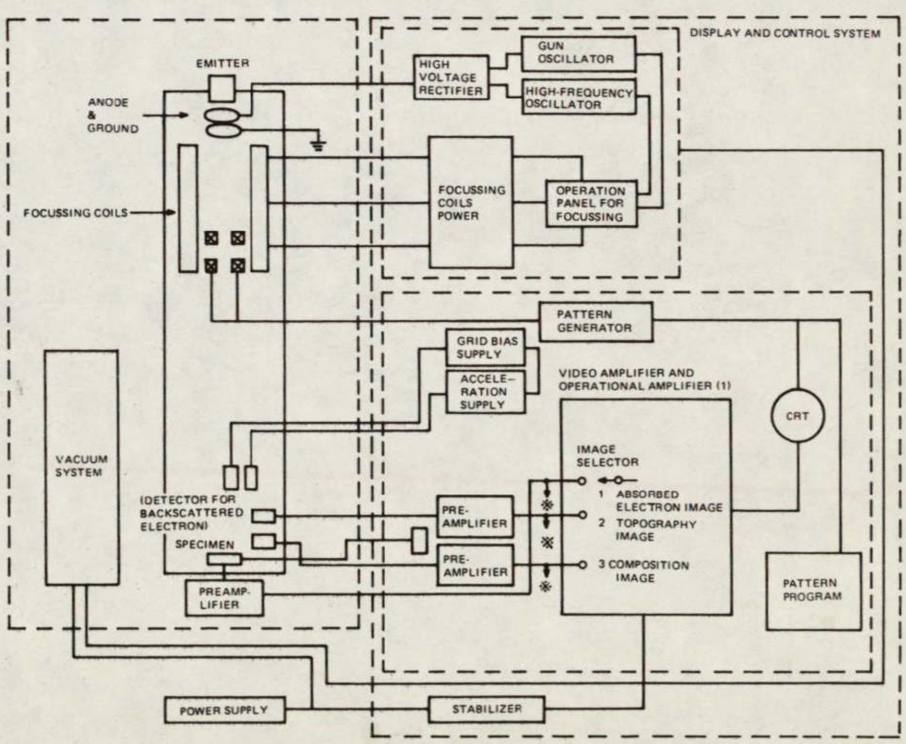


Figure II-16. Concept of Modified Electron Beam Microscope for Mask Pattern "Writing"

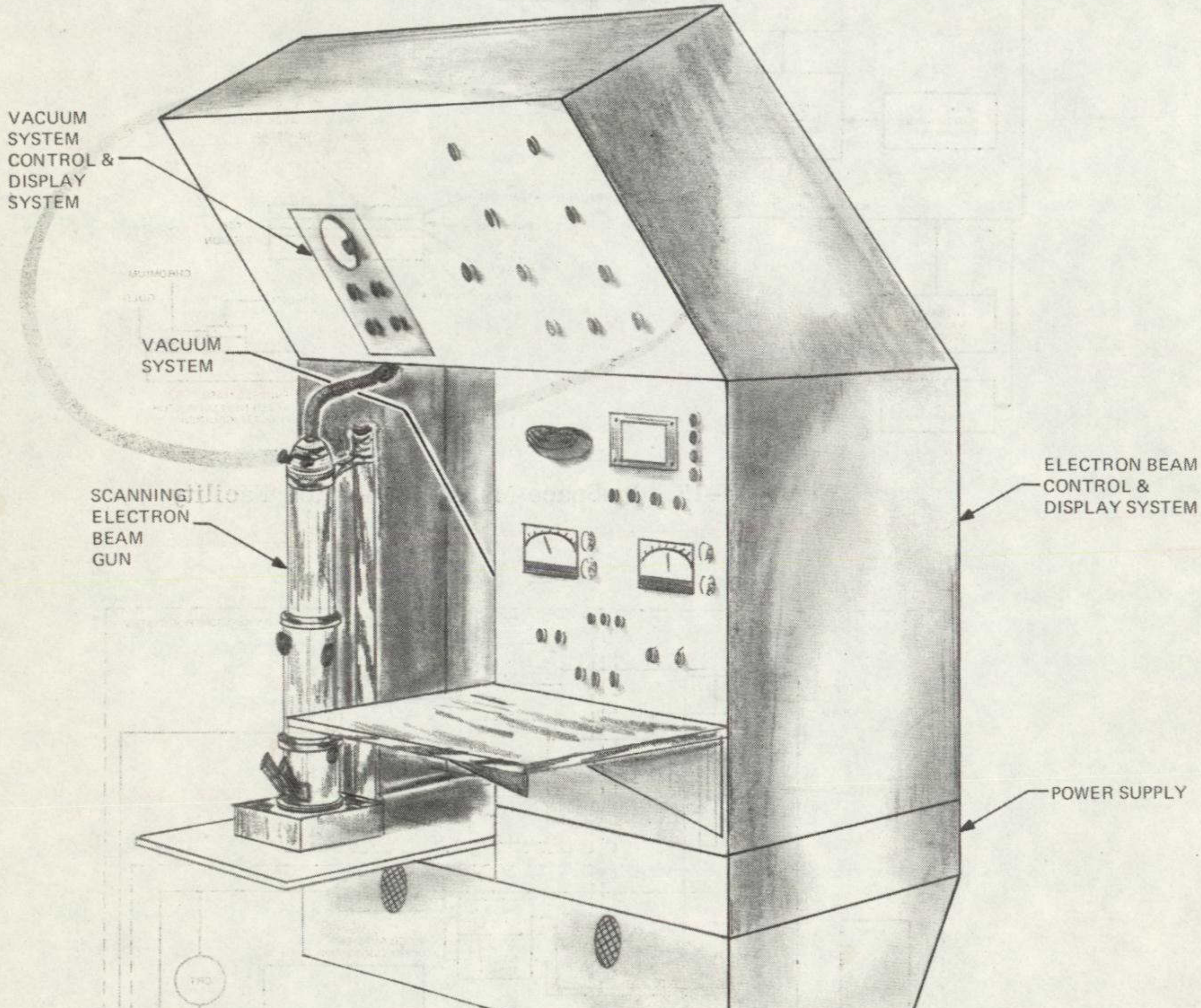


Figure II-17. Concept of Mask-Cutting Facility in Spacelab

II-2.6 CRYSTAL CUT & POLISH PROCESS STEP (GROUND) (WBS 6.0)

Crystals as received from the in-space crystal growing process (WBS 4.0) will be in the form of a boule, hopefully of a diameter and crystalline structure such that crystal wafers of 3-4 cm diameter can be cut from the boule with minimum waste and limited lap and polishing requirements. An R&D effort is required to establish this cutting and polishing process (ground facilities) with an end objective of optically polished flat (to $\lambda/20$), stress-free crystal wafers of 1-2 mm thickness suitable for imprinting >30,000 individual SAW circuit elements on a single 2mm x 2mm wafer. The crystal growing experiments will be closely interelated with the cut and polish process, which must necessarily adapt to the nature of the crystal boule. The cut and polish investigations and equipment/process design will be based on application of conventional ground based techniques for optical glass cutting and polishing.

The pilot/production facility will provide a capability for cutting 3000-6000 wafers per year from a total boule length of perhaps 700-1000 cm. Waste factors (cutting) and yield (% acceptable after cutting and polishing) will be important factors in the economic feasibility of SAW devices, since the User's experience has shown that yield factors on new crystals can run as low as 10%.

II.2.7 CRYSTAL CLEAN, METALIZE & RESIST PROCESS (GROUND) (WBS 7.0)

An R&D effort is required to design, develop and test a ground process for preparing crystal wafers for the subsequent x-ray exposure process (WBS 8.0). The clean, metalize and resist process, Figure II-18, is nominally as follows, for a crystal wafer or batch:

Install	5 min.
Clean (ion beam or back sputter)	2-5 min.
Metalize (vapor deposition)	
Chromium flash coating	1 min.
Aluminum surfacing	5 min.
Resist Coating (spray or dip/spin)	30 min.
(evacuation, coating, bake-out)	
Subtotal	46 min.
Handling, etc.	14 min.
Total	60 min.

This sequence suggests either an automatic continuous process or a batch (e.g. 9 wafers in a batch) process, to achieve acceptable throughput. The research and development sequence will consist of ground lab tests of ultra-cleaning, metallization, resist application and, where needed, piezoelectric film deposition. The prototype process will establish automated or batch processes as required to anticipate production throughput problems.

II.2.8 CRYSTAL MASK & EXPOSE PROCESS (GROUND) (WBS 8.0)

The x-ray exposure Figure II-19, of a prepared (resist-coated) crystal requires about 3 minutes. Thus a single-station for x-ray exposure (4-5 cm beam width) could have a throughput of 20 wafers (3-4 cm diameter) per hour, which is compatible with an annual throughput of 3000 wafers/yr. Additional stations could be added if necessary to increase throughput. An R&D effort is required to examine the basic phenomenology and to design equipment associated with mask alignment/positioning, soft x-ray (100 A^{o}) exposure lithographic techniques, vibration tolerances and isolation, and handling methods. These examinations would be conducted in a ground laboratory. The masks and crystal wafers required for these tests would be provided as outputs of tasks 4.0 and 5.0, respectively.

II.2.9 CRYSTAL DEVELOP, ETCH, CLEAN & TEST PROCESS (GROUND) (WBS 9.0)

The crystal wafer photo-developing step would be a conventional process using an acetone bath under a suitably vented hood. The etch and clean station would be adjacent to the developing station, with a similar bath, hood and vent system, plus a dry nitrogen line and ultrasonic cleaner. Throughput of these two stations could be 100 wafers per day, with one operator.

Cutting of the crystal wafer into 100-200 2 x 2 mm chips would be done with a multiple string saw or quartz crystal cutting equipment. A gang saw of nominally 15 strings could cut a 3-4 cm wafer into chips with one x-axis and one y-axis cut, which at a

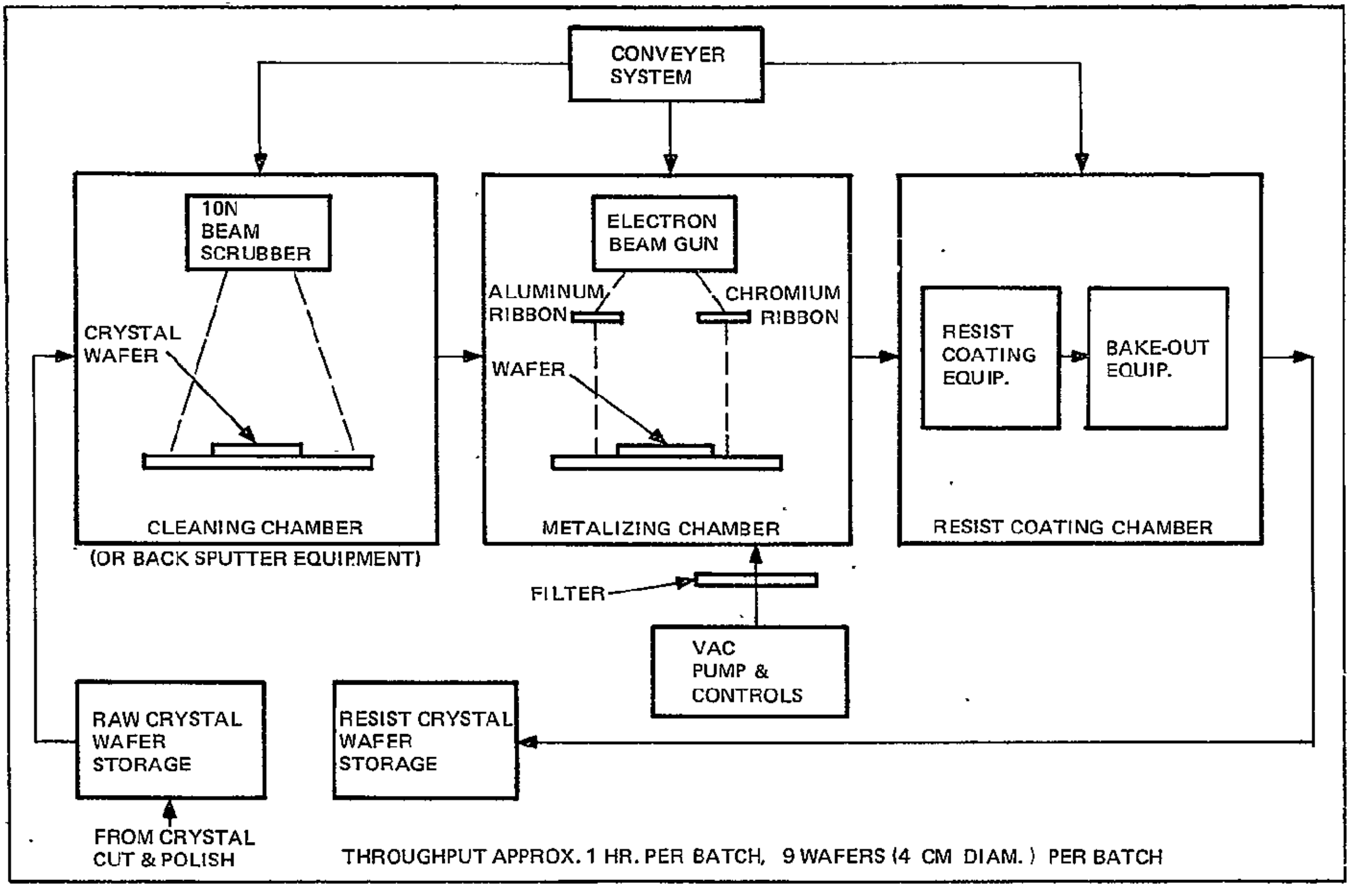


Figure II-18. Ground Facility - Crystal Wafer Clean, Metalize and Resist

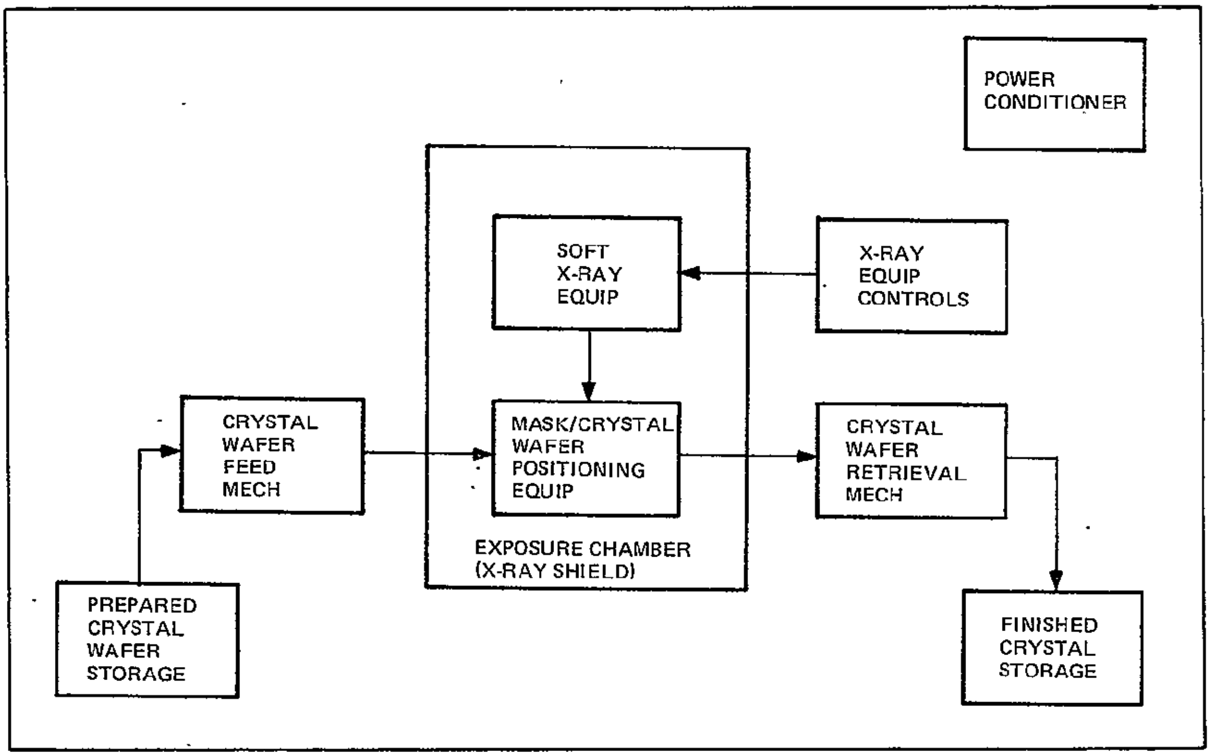


Figure II-19. Crystal Wafer Mask and X-Ray Expose Facility

0.5 cm/minute cutting rate, would require 16 minutes per wafer. Thus, one wafer cutting work stations (3-4) would be required, to provide a throughput of up to 100 wafers per day.

The individual chips would be held on a wafer holder by a wax substrate, until released by warming of the wax and removal by a test operator for cleaning and testing. After ultra-sonic cleaning, the individual 2 x 2 mm chip would be placed in an epoxy case, be fitted with nominally 4 input/output leads, tested, and sealed in the case with an epoxy cover (heat seal). Operators would use low-power stereo microscopes for this work. At a throughput of 20 devices per hour, per operator, about 7 operator positions for package and test would be required to achieve an annual throughput of 250,000 SAW devices per year.

The techniques involved in the above processes are conventional and so the R&D effort would consist primarily in establishing pre-prototype and prototype small-scale positions to confirm the processes used and to determine the SAW device performance, reliability and yield factor. Pilot/production scale-up should be via increase of the number of work stations, with the addition of automated test equipment for rapid device testing.

II.3 DEVELOPMENT SCHEDULE

The major activities required and their phasing are as follows:

		Year
1.	Analysis and Planning	1973 - 1975
2.	Laboratory Experiments	1974 - 1977
3.	Special Equipment Development	1975 - 1980
4.	Shuttle Verification Testing	1980 - 1982
5.	Operational Demonstration (Pilot)	1982 - 1985
6.	Full Operational Production in Space	1985 & beyond

The detailed development schedule is shown in Figure II-20.

Laboratory experiments in the 1974-1977 period are primarily aimed at acquiring basic information on the fundamental problems of electron beam writing of circuits (beamwidth) control and flux distribution, vibration isolation, etc.), and on the basic crystal problems (selection of materials and crystal growing method).

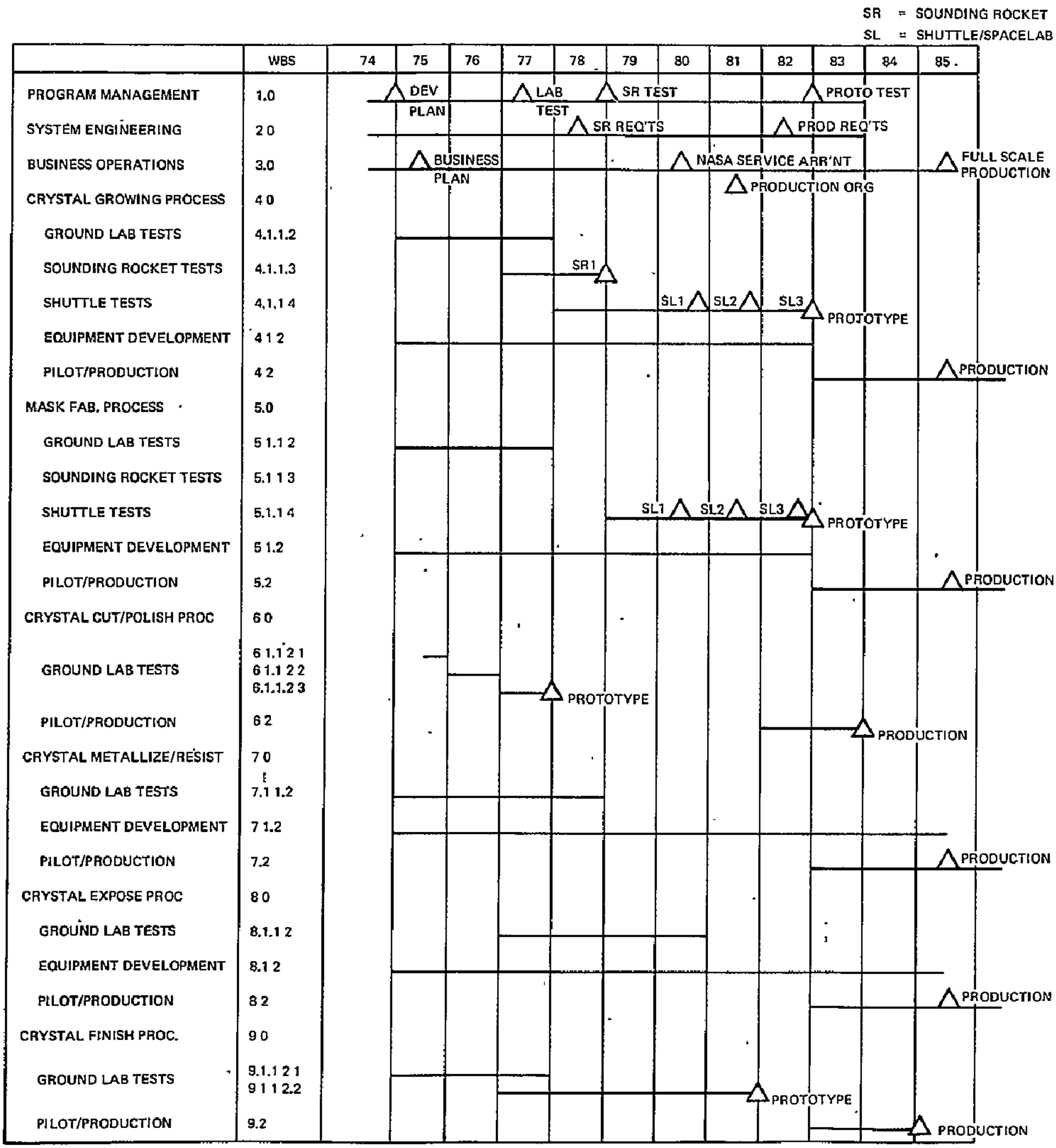


Figure II-20. Surface Acoustic Wave Development Schedule

SECTION III

RESOURCES PLANNING

As in the preceding section, which extracted the program activities, their key milestones and timing, from the documented Work Elements in order to provide Development Planning data, we also analyzed the Resource Requirements and Resource Costs documents to extract the Resource Planning data.

Based on these requirements and costs, we have delineated the planned allocation of development costs for the Surface Acoustic Wave device program under study. For programmatic purposes, these allocations have been assembled under several combinations of categories: type of resource, WBS elements, timing, and for both Case A and Case B.

A summary of the estimated costs for Case A, broken down by major resource category, is shown in Figure III-1 for each major WBS Element and in Figures III-2A and B for lower level WBS elements. The $14.3 million total program cost includes the cost of NASA service charges for Sounding Rockets, and Shuttle flights in the R&D phase.

A time-phased statement of those same costs for Case A is given in Figure III-3, with Figure III-4A and B broken down to the lower levels of WBS elements.

Case B costs for R&D (wherein the User does not bear the proof-of-process-feasibility costs) are shown in Figures III-5, 6A and 6B. User costs in this case are estimated at $4.6 m.

It is important to recognize that costs are, in some cases, only measures of resources such as personnel with key skills, facilities, special equipment, etc. A tabulation of such resources by WBS element is shown in Figure III-7.

WBS	Task	Labor Cost	Purch. Mat'ls Cost	Services Cost	Equip. Cost	Facilities Cost	Total Cost	Time Period
1.1	Program Management	1302K	-	-	-	-	1302K	75-82
2.1	System Engineering	1184K	-	-	-	-	1184K	75-82
3.1	Business Operations	-	-	-	-	-	-	-
4.1	Crystal Growing Process	1204K	72K	2600K	64K	-	3940K	75-82
5.1	Mask Fabrication Process	1217K	62K	3880K	282K	-	5441K	75-82
6.1	Crystal Cut and Polish Process	449K	10K	1K	401K	-	861K	75-77
7.1	Crystal Clean, Metalize, Resist.	597K	11K	7K	10K	-	625K	75-82
8.1	Crystal Mask and Expose Proc.	261K	23K	3K	56K	-	343K	77-80
9.1	Crystal Dev., Etch, Clean, Test.	489K	11K	3K	125K	-	628K	75-82
	Totals	6703K	189K	6494K	938K		14324K	

Figure III-1. Case A - SAW Device R&D Program Cost Summary (By Cost Element)

WBS	Task	Labor Cost	Purch. Mat'ls Cost	Services Cost	Equip. Cost	Facilities Cost	Total Cost	Time Period
1.1	Program Management	1302K	-	-	-	-	1302K	75-83
2.1	System Engineering	1184K	-	-	-	-	1184K	75-83
3.1	Business Operations	-	-	-	-	-	-	-
4.1	Crystal Growing Process	1204K	72K	2600K	64K	-	3940K	75-82
4.1.1	Process Dev.	1204K	72K	2600K	64K	-	3940K	75-82
4.1.1.1	Project Supervision	358K	-	-	-	-	358K	75-82
4.1.1.2	Ground Lab Tests	150K	35K	10K	15K	-	210K	75-77
4.1.1.2.1	Crystal Growing Techniques 1-G	150K	35K	10K	15K	-	210K	75-77
4.1.1.3	Sounding Rocket Tests	-	-	-	-	-	-	-
4.1.1.4	Shuttle Tests	696K	37K	2590K	49K	-	3372K	77-82
4.1.1.4.1	Crystal Growing Techniques 0-G	696K	37K	2590K	49K	-	3372K	77-82
4.1.2	Equip. Dev.	-	-	-	-	-	-	77-79
5.1	Mask Fabrication Process	1217K	62K	3880K	282K	-	5441K	75-82
5.1.1	Process Dev.	1217K	62K	3880K	282K	-	5441K	75-82
5.1.1.1	Project Supervision	494K	-	-	-	-	494K	75-82
5.1.1.2	Ground Lab Tests	108.0K	6.0K	4.0K	39.0K	-	157.0K	75-77
5.1.1.2.1	Electron Beam Resolution	67.0K	3.0K	3.0K	35.0K	-	108.0K	75-77
5.1.1.2.2	Vibration Analysis	41.0K	3.0K	1.0K	4.0K	-	49.0K	76-77
5.1.1.3	Sounding Rocket Tests	-	-	-	-	-	-	75-77
5.1.1.4	Shuttle Tests	615.0K	56.0K	3876K	243.0K	-	4790K	78-82
5.1.1.4.1	Mask Fab Tests 0-G	615.0K	56.0K	3876K	243.0K	-	4790K	78-82
5.1.2	Equip. Dev.	-	-	-	-	-	-	
6.1	Crystal Cut and Polish Process	448.8K	10.1K	0.5K	401.5K	-	860.9K	75-77
6.1.1	Process Dev.	448.8K	10.1K	0.5K	401.5K	-	860.9K	75-77
6.1.1.1	Project Supervision	78.3K	-	-	-	-	78.3K	75-77
6.1.1.2	Ground Lab Tests	370.5K	10.1K	0.5K	401.5K	-	782.6K	75-77
6.1.1.2.1	Basic Phenomenology	43.5K	3.1K	-	-	-	46.6K	75
6.1.1.2.2	Process Dev.	72.0K	3.0K	-	201.5K	-	276.5K	75-76
6.1.1.2.3	Prototype Process	255.0K	4.0K	0.5K	200.0K	-	459.5K	76-77
6.1.2	Equip. Dev.	-	-	-	-	-	-	75-77
7.1	Crystal Clean, Metalize, Resist Process	596.8K	11.5K	6.5K	10.0K	-	624.8K	75-82
7.1.1	Process Dev.	596.8K	11.5K	6.5K	10.0K	-	624.8K	75-82
7.1.1.1	Project Supervision	56.8K	-	-	-	-	56.8K	75-82
7.1.1.2	Ground Lab Tests	540.0K	11.5K	6.5K	10.0K	-	568.0K	75-78
7.1.1.2.1	Ultra Cleaning Test	50K	2K	-	-	-	52K	75-76
7.1.1.2.2	Metalization Tests	15K	1K	-	-	-	16K	75-76
7.1.1.2.3	Resist Tests	235.0K	4.0K	5.0K	10.0K	-	254.0K	75-77
7.1.1.2.4	Piezo Film Deposition Tests	240.0K	4.5K	1.5K	-	-	246.0K	75-78
7.1.2	Equip. Dev.	-	-	-	-	-	-	75-78

Figure III-2A. Case A Surface Acoustic Wave Device Development Program Summary (Page 1 of 2)

WBS	Task	Labor Cost	Purch. Mat'ls Cost	Services Cost	Equip. Cost	Facilities Cost	Total Cost	Time Period
8.1	Crystal Mask and Expose Process	261K	23K	3K	56K	-	343K	77-80
8.1.1	Process Dev.	224K	20K	3K	15K	-	262K	77-80
8.1.1.1	Project Supervision	24K	-	-	-	-	24K	77-80
8.1.1.2	Ground Lab Tests	200.0K	20.0K	3.0K	15.0K	-	238.0K	77-80
8.1.1.2.1	Vibration Tests	200.0K	20.0K	3.0K	15.0K	-	238.0K	77-80
8.1.2	Equip. Dev.	37.0K	3.0K	-	41.0K	-	81.0K	77-80
9.1	Crystal Dev., Etch, Clean Test Process	489.1K	11.0K	3.0K	125.0K	-	628.1K	75-82
9.1.1	Process Dev.	489.1K	11.0K	3.0K	125.0K	-	628.1K	75-77
9.1.1.1	Project Supervision	57.1K	-	-	-	-	57.1K	75-77
9.1.1.2	Ground Lab Tests	432.0K	11.0K	3.0K	125.0K	-	571.0K	75-77
9.1.1.2.1	Basic Phenomenalogy	80.0K	2.0K	1.0K	-	-	83.0K	75-77
9.1.1.2.2	Process Dev.	352.0K	9.0K	2.0K	125.0K	-	488.0K	77-80
9.1.2	Equip. Dev.	-	-	-	-	-	-	75-80
	Total	6703K	189K	6494K	938K	-	14324K	

Figure III-2B. Case A - Surface Acoustic Wave Device Development Program Summary (Page 2 of 2)

WBS	Task	Total Cost	75	76	77	78	79	80	81	82
1.1	Program Management	1302K	45K	103K	109K	93K	61K	310K	296K	285K
2.1	System Engineering	1184K	41K	93K	99K	85K	56K	282K	270K	258K
3.1	Business Operations	-	-	-	-	-	-	-	-	-
4.1	Crystal Growing Process	3940K	110K	66K	275K	211K	110K	1056K	1056K	1056K
5.1	Mask Fabrication Process	5441K	66K	63K	44K	220K	242K	1638K	1639K	1529K
6.1	Crystal Cut and Polish Process	861K	107K	513K	241K	-	-	-	-	-
7.1	Crystal Clean, Metalize, Resist	625K	121K	233K	209K	62K	-	-	-	-
8.1	Crystal Mask & Expose Process	343K	-	-	106K	126K	71K	40K	-	-
9.1	Crystal Dev., Etch, Clean, Test	628K	6K	59K	119K	226K	133K	85K	-	-
	Totals	14324K	496K	1130K	1202K	1023K	673K	3411K	3261K	3128K

Figure III-3. Case A - SAW Device R&D Program Summary (By Year)

WBS	Task	Total	75	76	77	78	79	80	81	82	83	84	85
1.1	Program Management	1302K	45K	103K	109K	93K	61K	310K	296K	285K	-	-	-
2.1	System Engineering	1184K	41K	93K	99K	85K	56K	282K	270K	258K	-	-	-
3.1	Business Operations	-	-	-	-	-	-	-	-	-	-	-	-
4.1	Crystal Growing Process	3940K	110K	66K	275K	211K	110K	1056K	1056K	1056K	-	-	-
4.1.1	Process Development	3940K	110K	66K	275K	211K	110K	1056K	1056K	1056K	-	-	-
4.1.1.1	Project Supervision	358K	10K	6K	25K	19K	10K	96K	96K	96K	-	-	-
4.1.1.2	Ground Lab Tests	210K	100K	60K	50K	-	-	-	-	-	-	-	-
4.1.1.2.1	Crystal Growing Techniques, 1-G	210K	100K	60K	50K	-	-	-	-	-	-	-	-
4.1.1.3	Sounding Rocket Tests	-	-	-	-	-	-	-	-	-	-	-	-
4.1.1.4	Shuttle Tests	3372K	-	-	200K	192K	100K	960K	960K	960K	-	-	-
4.1.1.4.1	Crystal Growing Techniques, 0-G	3372K	-	-	200K	192K	100K	960K	960K	960K	-	-	-
4.1.2	Equip. Development	-	-	-	-	-	-	-	-	-	-	-	-
5.1	Mask Fabrication Process	5441K	66K	63K	44K	220K	242K	1638K	1639K	1529K	-	-	-
5.1.1	Process Development	5441K	66K	63K	44K	220K	242K	1638K	1639K	1529K	-	-	-
5.1.1.1	Project Supervision	494K	6K	6K	4K	20K	22K	148K	149K	139K	-	-	-
5.1.1.2	Ground Lab Tests	157K	60K	57K	40K	-	-	-	-	-	-	-	-
5.1.1.2.1	Electron Beam Resolution	108K	60K	28K	20K	-	-	-	-	-	-	-	-
5.1.1.2.2	Vibration Analysis	49K	-	29K	20K	-	-	-	-	-	-	-	-
5.1.1.3	Sounding Rocket Tests	-	-	-	-	-	-	-	-	-	-	-	-
5.1.1.4	Shuttle Tests	4790K	-	-	-	200K	220K	1490K	1490K	1390K	-	-	-
5.1.1.4.1	Mask Fab Tests, 0-G	4790K	-	-	-	200K	220K	1490K	1490K	1390K	-	-	-
5.1.2	Equip. Development	-	-	-	-	-	-	-	-	-	-	-	-
6.1	Crystal Cut and Polish Process	861K	107K	513K	241K	-	-	-	-	-	-	-	-
6.1.1	Process Development	861K	107K	513K	241K	-	-	-	-	-	-	-	-
6.1.1.1	Project Supervision	78K	10K	46K	22K	-	-	-	-	-	-	-	-
6.1.1.2	Ground Lab Tests	783K	97K	467K	219K	-	-	-	-	-	-	-	-
6.1.1.2.1	Basic Phenomenology	47K	47K	-	-	-	-	-	-	-	-	-	-
6.1.1.2.2	Process Dev.	277K	50K	227K	-	-	-	-	-	-	-	-	-
6.1.1.2.3	Prototype Process	459K	-	240K	219K	-	-	-	-	-	-	-	-
6.1.2	Equipment Development	-	-	-	-	-	-	-	-	-	-	-	-
7.1	Crystal Clean, Metalize, Resist Proc.	625K	121K	233K	209K	62K	-	-	-	-	-	-	-
7.1.1	Process Development	625K	121K	233K	209K	62K	-	-	-	-	-	-	-
7.1.1.1	Project Supervision	57K	11K	21K	19K	6K	-	-	-	-	-	-	-
7.1.1.2	Ground Lab Tests	568K	110K	212K	190K	56K	-	-	-	-	-	-	-
7.1.1.2.1	Ultra Cleaning Tests	52K	10K	42K	-	-	-	-	-	-	-	-	-
7.1.1.2.2	Metalization Tests	16K	-	16K	-	-	-	-	-	-	-	-	-
7.1.1.2.3	Resist Tests	254K	80K	74K	100K	-	-	-	-	-	-	-	-
7.1.1.2.4	Piezo Film Deposition Tests	246K	20K	80K	90K	56K	-	-	-	-	-	-	-
7.1.2	Equipment Development	-	-	-	-	-	-	-	-	-	-	-	-

Figure III-4A. Case A - SAW Device R&D Program (Including Space Charges) WBS Element By Year (Sheet 1 of 2)

WBS	Task	Total	75	76	77	78	79	80	81	82	83	84	85
8.1	Crystal Mask and Expose Process	343K	-	-	106K	126K	71K	40K	-	-	-	-	-
8.1.1	Process Development	262K	-	-	86K	86K	56K	34K	-	-	-	-	-
8.1.1.1	Project Supervision	24K	-	-	6K	6K	6K	6K	-	-	-	-	-
8.1.1.2	Ground Lab Tests	238K	-	-	80K	80K	50K	28K	-	-	-	-	-
8.1.1.2.1	Vibration Tests	238K	-	-	80K	80K	50K	28K	-	-	-	-	-
8.1.2	Equipment Development	81K	-	-	20K	40K	15K	6K	-	-	-	-	-
9.1	Crystal Dev., Etch, Clean, Test Process	628K	6K	59K	119K	226K	133K	85K	-	-	-	-	-
9.1.1	Process Development	628K	6K	59K	119K	226K	133K	85K	-	-	-	-	-
9.1.1.1	Project Supervision	57K	1K	9K	11K	16K	13K	7K	-	-	-	-	-
9.1.1.2	Ground Lab Tests	571K	5K	50K	108K	210K	120K	78K	-	-	-	-	-
9.1.1.2.1	Basic Phenomenology	83K	5K	50K	28K	-	-	-	-	-	-	-	-
9.1.1.2.2	Process Development	488K	-	-	80K	210K	120K	78K	-	-	-	-	-
9.1.2	Equipment Development	-	-	-	-	-	-	-	-	-	-	-	-
	TOTALS	14324K	496K	1130K	1202K	1023K	673K	3411K	3261K	3128K	-	-	-

Figure III-4B. Case A - SAW Device R&D Program (Including Space Charges) WBS Element By Year (Sheet 2 of 2)

WBS	Task	Total	75	76	77	78	79	80	81	82
1.1	Program Management	415K	-	29K	36K	25K	22K	14K	85K	204K
2.1	System Engineering	376K	-	26K	33K	23K	20K	12K	77K	185K
3.1	Business Operations	-	-	-	-	-	-	-	-	-
4.1	Crystal Growing Process	1060K	-	-	-	-	-	-	84K	976K
5.1	Mask Fabrication Process	1564K	-	-	-	-	-	-	122K	1442K
6.1	Crystal Cut and Polish Process	505K	-	264K	241K	-	-	-	-	-
7.1	Crystal Clean, Metalize, Resist Proc.	-	-	-	-	-	-	-	-	-
8.1	Crystal Mask & Expose Process	109K	-	-	-	-	72K	37K	-	-
9.1	Crystal Dev., Etch, Clean, Test Proc.	537K	-	-	88K	231K	132K	86K	-	-
	Totals	4566	-	319K	398K	279K	246K	149K	368K	2807K

Figure III-5. Case B - SAW Device R&D Program Summary

WBS	Task	Total	75	76	77	78	79	80	81	82	83
1.1	Program Management	415K	-	29K	36K	25K	22K	14K	85K	204K	-
2.1	System Engineering	376K	-	26K	33K	23K	20K	12K	77K	185K	-
3.1	Business Operations	-	-	-	-	-	-	-	-	-	-
4.1	Crystal Growing Process	1060K	-	-	-	-	-	-	84K	976K	-
4.1.1	Process Development	1060K	-	-	-	-	-	-	84K	976K	-
4.1.1.1	Project Supervision	96K	-	-	-	-	-	-	30K	66K	-
4.1.1.2	Ground Lab Tests	-	-	-	-	-	-	-	-	-	-
4.1.1.2.1	Crystal Growing Tech, 1-G	-	-	-	-	-	-	-	-	-	-
4.1.1.3	Sounding Rocket Tests	-	-	-	-	-	-	-	-	-	-
4.1.1.4	Shuttle Tests	964K	-	-	-	-	-	-	54K	910K	-
4.1.1.4.1	Crystal Growing - 0-G (Flt #3)	964K	-	-	-	-	-	-	54K	910K	-
4.1.2	Equip Dev.	-	-	-	-	-	-	-	-	-	-
5.1	Mask Fabrication Process	1564K	-	-	-	-	-	-	122K	1442K	-
5.1.1	Process Development	1564K	-	-	-	-	-	-	122K	1442K	-
5.1.1.1	Project Supervision	142K	-	-	-	-	-	-	40K	102K	-
5.1.1.2	Ground Lab Tests	-	-	-	-	-	-	-	-	-	-
5.1.1.2.1	Electron Beam Resolution	-									
5.1.1.2.2	Vibration Analysis	-									
5.1.1.3	Sounding Rocket Tests	-	-	-	-	-	-	-	-	-	
5.1.1.4	Shuttle Tests	1422K	-	-	-	-	-	-	82K	1340K	-
5.1.1.4.1	Mask Fabrication, 0-G (Flt #3)	1422K	-	-	-	-	-	-	82K	1340K	
5.1.2	Equip. Dev.	-	-	-	-	-	-	-	-	-	
6.1	Crystal Cut and Polish Process	505K	-	264K	241K	-	-	-	-	-	-
6.1.1	Process Development	505K	-	264K	241K	-	-	-	-	-	-
6.1.1.1	Project Supervision	46K	-	24K	22K	-	-	-	-	-	-
6.1.1.2	Ground Lab Tests	459K	-	240K	219K	-	-	-	-	-	-
6.1.1.2.1	Basic Phenomenology	-									
6.1.1.2.2	Process Dev.	-		-	-	-	-	-	-	-	-
6.1.1.2.3	Prototype Process	459K	-	240K	219K	-	-	-	-	-	-
6.1.2	Equipment Dev.	-	-	-	-	-	-	-	-	-	-
7.1	Crystal Clean, Metalize, Resist Proc.	-									
7.1.1	Process Development	-									
7.1.1.1	Project Supervision	-									
7.1.1.2	Ground Lab Tests	-									
7.1.1.2.1	Ultra Cleaning Tests	-									
7.1.1.2.2	Metalization Tests	-									
7.1.1.2.3	Resist Tests	-									
7.1.1.2.4	Piezo Film Deposition Tests	-									
7.1.2	Equipment Dev.	-									

Figure III-6A. Case B - SAW Device User R&D Program (Where NASA Establishes Process Feasibility)

WBS	Task	Total	75	76	77	78	79	80	81	82	83
8.1	Crystal Mask and Expose Process	109K	-	-	-	-	72K	37K	-	-	-
8.1.1	Process Development	88K					57K	31K	-	-	-
8.1.1.1	Project Supervision	10K					7K	3K	-	-	-
8.1.1.2	Ground Lab Tests	78K					50K	28K	-	-	-
8.1.1.2.1	Vibration Tests	78K					50K	28K	-	-	-
8.1.2	Equip. Dev.	21K					15K	6K	-	-	-
9.1	Crystal Dev. Etch, Clean, Test Proc.	537K	-	-	88K	231K	132K	86K	-	-	-
9.1.1	Process Development	537K			88K	231K	132K	86K			
9.1.1.1	Project Supervision	49K	-	-	8K	21K	12K	8K	-	-	-
9.1.1.2	Ground Lab Tests	488K									
9.1.1.2.1	Basic Phenomenology	-									
9.1.1.2.2	Process Dev.	188K	-	-	80K	210K	120K	78K	-	-	-
9.1.2	Equipment Dev.	-									
	TOTALS	4566K	-	319K	398K	279K	246K	149K	368K	2807K	-

Figure III-6B. Case B - SAW Device User R&D Program (Where NASA Establishes Process Feasibility)

WBS	Task	Period (Yrs.)	Special Skills	Materials	Services	Equipment	Facilities
1.1	Program Management	75 82	-	-	Conventional.	N/A	Conventional
2 1	System Engineering	75 82	-	-	Customer technical direction, marketing requirements, Orbiter characteristics	N/A	Conventional
3 1	Business Operations	75 82	-	-	Market surveys, forecasts, catalog/sales literature, management, policies	N/A	Conventional
4 1	Crystal Growing Process						
4 1 1	Process Development	75 82	Crystal growing specialist/ technician Microwave engr/tech.	Crystal growing materials (e g , lithium niobate, sapphire, quartz, diamond) space grown boule or chips	Initial space crystals materials, tests, process/prototype designs Crystal characterization services. High frequency SAW utilization tests	Pre prototype and prototype process apparatus X-ray diffractors electron micro scope, photo equipment, etc.	Standard crystal growing lab facilities with optical, microwave and computer services to evaluate 1g crystals.
4.1 2	Equipment Development	77-79	Crystal growing equipment specialist (eng/tech)	(Same as 4.1.1)	Crystal characterization services	Crystal growing, potting, cutting/polishing equipment Instrumentation.	Conventional equipment devices, lab with vacuum, inert gas, power.
5.1	Mask Fabrication Process						
5.1.1	Process Development						
5 1.1 2	Ground Lab Test	75 82	Vibration engr/tech Electron Beam engr/tech. Optical engineer.	General electrical and chemical supplies, photo supplies, optically flat substrates (glass & single crystals of glass, quartz, lithium niobate), Polymethyl methacrylate for resist. coating	Analysis of Orbiter vibration levels, Earth seismic levels. Computer time for vibration data and finger pattern defects analysis Optical analysis	Vibration simulators, substrate holding fixture, vacuum chamber, scanning electron microscope, x ray machine, electron beam writing device.	Standard shock/vibration lab, with vacuum, inert gas, power, facilities. Also, optical shop for optical and surface cleaning
5 1 1.3	Sounding Rocket Tests	N/A	N/A	N/A	N/A	N/A	N/A
5.1.1 4	Orbiter Tests	79 82	Electron Beam technician. Crystal technician.	Same as 5.1.1.2	Orbiter launch, in orbit and recovery services.	Same as for ground test lab except addition of EB writing automation and use of vibration isolators	Orbiter facilities for experiment such as space, vacuum, power, and computer.
5 1.2	Equipment Development	75 82	Optical design eng/tech	General optical and mechanical supplies.	Computer time.	Electron beam gun and power supply Mask positioning/ exposure/handling/inspection equipment.	Conventional optical equipment design development, fabrication lab.
6 1	Crystal Cut and Polish						
6.1 1	Process Development	75 82					
6 1.1 1	Ground Lab Tests	75 82	Crystal engr/tech.	Crystal boules (excellent commercial grade) General chemical, lapping polishing compounds.	N/A	X-ray orientation equipment, precision saw, lapping machine, flatness and smoothness test equipment.	Optical lab (well equipped with x ray equipment and clean working areas
6.1.2	Equipment Development		Conventional	-	-	-	Conventional

Figure III-7. SAW Device R&D Resource Needs Summary

A Sounding Rocket test in late 1978 is programmed for a key test on a method of positioning the molten crystal material during crystal growth. Shuttle/Spacelab tests form the backbone of testing the major process steps (crystal growth, mask fabrication) in 1980 to 1983. Low cost testing in this time frame will be very attractive to the User. If other crystal-growing and directional solidification experiments are carried out in this time frame, there should be considerable "Ruboff" for this program.

On the other hand, no other programs have indicated a strong need for low frequency vibration measurements, isolation equipment, or electron beam "Writing" development, and it appears that this program is likely to account for all needed resources to acquire such data and capabilities.

SECTION IV

CASH FLOW ANALYSIS

The data inputs and parameter values used in the baseline Case A, (User bears full R&D costs), cash flow analysis are shown in Figure IV-1. The financial forecast for this case for the period 1975-1992 is presented in Figures IV-2A and 2B. A total market demand of 2000 bandpass filters is projected in 1980, growing to 500,000 by 1987. The market share builds up to about 50% by 1982. The unit price per bandpass filter remains at $20 for all years, owing to the lack of a basis for profiling this value.

The same baseline information applies to Case B, Figure IV-3, except that the user-funded research and development program to establish a production capability after demonstration of process feasibility by NASA is estimated at about $4.6 million. The detailed cash flow of Case B is shown in Figure IV-4A and B.

Finally, for Case C, we have explored one of the potential "what if's" that could be conceived as alternative scenarios. As shown in Figures IV-5 and IV-6A and B, we have increased the unit price by 50%. Based on present day costs of bandpass filters, the $30 price is high, yet, considering that more complex subsystems can be contained on a Surface Acoustic Wave device, and that commercial millimeter wave communications are in the not too distant future, the price is not unreasonable.

Financial analysis was based on the estimation of the following 6 items over the period 1975-1992.

Total Market - demand for SAW bandpass filters based on the availability of a high quality, low cost device, and active use of the 10-30 GHz spectrum.

Market Share - percent of the total market to be satisfied by the producer, based on an estimated constant 50% share over the forecast period.

Unit Price - based on a relatively low, but feasible estimated price of $20, constant for the forecast period.

Unit Manufacturing Cost - based on an itemization of the process costs to produce SAW bandpass filters, including space and ground processing, space service charges, and final device packaging and test.

Research and Development Cost - based on an estimate of the ground lab and space shuttle/space lab experiments required to achieve a prototype process capability, including the boule-growing space process, master-mask space process, and the associated ground steps.

Annual Plant and Equipment - based on added equipment and existing plant expansion required. A ten-year straight line depreciation was used for purposes of analysis.

A simplified financial forecast routine was then used to determine the following business venture performance measures:

Percent Return on Investment (ROI) - This is calculated as the annual net profit (after taxes and before payment of dividends) divided by net annual investment. The significance of the return on investment measure is that it indicates the yield to the business after all costs are deducted. It can be compared on an annual basis to the return which might be obtained from alternate investment of the same funds, including the option of putting the money in a bank savings account. The Case B ROI obtained is 44% (1992), which is high, suggesting that actual results might be lower. However, this is a good indicator. Case C, with a higher unit price, shows an ROI of 85%, which is very high and unlikely to be achieved.

Percent Net Income to Sales - This is calculated as net profit (after taxes and before payment of dividends) divided by annual sales. The significance of the net income to sales percent is that it indicates the yield relative to the amount of business (sales) being conducted, for comparison with what yield that type of business normally expects to achieve. The figure obtained for Case B is 20% (1992), which is well above the electronics industry average of 4.5% (in 1973).

Cumulative Cash Flow - This is the summation of the annual amounts of money which must be put into (or can be taken out of) the business over the forecast period. Annual cash flows are determined as the annual net income after taxes less the annual net change in investment. The summation of the annual cash flows over time gives the cumulative cash flow. In general, the sooner that a business

can generate positive cash flow (excess cash), the more attractive the venture. In the years when annual cash flow is positive, the business is generating more cash than is needed to operate the business. At the time when cumulative cash flow turns positive, the business will have paid back all of the money put into the business up to that time (breakeven point). The cumulative cash flow for Case B turns positive in 1991, 16 years after first expenditures, which is an unacceptable indicator. Case C breaks even in 13 years, still a poor indicator. These cases are strongly impacted by the long R&D program period (1975 to 1982). No attempt was made in this study to re-phase the R&D tasks to improve the breakeven period, but this area should be examined before drawing any firm conclusions on the SAW device venture.

Present Value - Present value is a measure of the worth today of funds expected to be paid out or received in the future, based on a chosen discount rate. The present value of the business is calculated by discounting the annual cash flows at a rate of 10 percent. The net annual investment in the last year of the forecast period, which can be taken as a measure of the liquidation value of the business, was included in the calculation. The present value indicated by Case B is (negative) $0.7 million, while the present value of Case C is (positive) $2.1 million. The significance of the present value measure is that, at zero present value, a business man is indifferent (theoretically) as to whether he puts his money in the bank at interest (at the assumed discount rate) or into the business (disregarding business risk). For a positive present value, he would rather put his money into the business.

Constants were established for calculation of costs other than those inputted, as shown in Figures IV-1, -3, and -5. Space charges based on the BUS Phase III model were included in the R&D and production costs. The two-step space processing feature of SAW devices (for crystal growing and master-mask cutting) makes the venture quite sensitive to space service charges.

Changes in assumptions could be made to increase the attractiveness of this conceptual venture:

- Increase unit price (Case C shows this effect)
- Decrease unit manufacturing cost

- Increase market size

- Increase market share

The high uncertainty associated with the estimates used for these items suggests that further exploration of the elements that affect them is necessary before judging this venture, since changes in these estimates can change the venture from unattractive to attractive.

Figure IV-7 plots the financial measures of profitability for the SAW venture.

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S A W D E V I C E S C A S E A

INPUT VALUES

INPUTS:	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	2000.	3000.	20000.	50000.	100000.
MARKET SHARE (PCT)	0.	0.	0.	0.	0.	0.	0.	50.	50.	50.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	20.	20.	20.
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	7.66	7.66	7.66
R AND D EXPENSE	496000.	1130000.	1202000.	1023000.	673000.	3411000.	3261000.	3128000.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	135000.	125000.	120000.

INPUTS:	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	300000.	400000.	500000.	500000.	500000.	500000.	500000.	500000.	0.	0.
MARKET SHARE (PCT)	50.	50.	50.	50.	50.	50.	50.	50.	0.	0.
UNIT PRICE	20.	20.	20.	20.	20.	20.	20.	20.	0.	0.
UNIT MANUFACTURING COST	7.66	7.66	7.66	7.66	7.66	7.66	7.66	7.66	.00	.00
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ANNUAL PLANT AND EQUIP.	120000.	120000.	0.	0.	0.	0.	1080000.	135000.	0.	0.

PARAMETRIC PERCENTAGES:

PARAMETER	IDENTIFIER	VALUE	PARAMETER	IDENTIFIER	VALUE
INTEREST RATE	P11	10.00	UNITS MANUFACTURED PCT.	P21	120.00
AVERAGE INVENTORY PCT.	P23	20.00	ENGINEERING EXPENSE PCT.	P26	5.00
SELLING EXPENSE PCT.	P27	5.00	ADMINISTRATION EXPENSE PCT	P28	10.00
RECEIVABLES PCT.	P31	20.00	DEPRECIATION PERIOD(YRS)	P35	10.00
OTHER INVESTMENT PCT.	P38	5.00			

PERCENTAGE OF BASELINE USED			ADD/SUB FROM BASELINE INPUTS	
INPUTS	IDENTIFIER	PCT	IDENTIFIER	VALUE
TOTAL MARKET	X1	100	A1	0.
MARKET SHARE	X2	100	A2	0.
UNIT PRICE	X3	100	A3	.00
UNIT MANUFACTURING COST	X4	100	A4	0.
R AND D EXPENSE	X5	100	A5	0.
ANNUAL PLANT AND EQUIP.	X6	100	A6	0.

Figure IV-1. Case A - SAW Devices Input Values

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S A W D E V I C E S C A S E A
C A S H F L O W A N A L Y S I S

	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	2000.	3000.	20000.	50000.	100000.
MARKET SHARE (PCT)	.00	.00	.00	.00	.00	.00	.00	50.00	50.00	50.00
UNITS SOLD (UNITS)	0.	0.	0.	0.	0.	0.	0.	10000.	25000.	50000.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	20.	20.	20.
SALES	0.	0.	0.	0.	0.	0.	0.	200000.	500000.	1000000.
OPERATING EXPENSES	496000.	1130000.	1202000.	1023000.	673000.	3411000.	3369000.	3365208.	423270.	724540.
GROSS PROFITS	-496000.	-1130000.	-1202000.	-1023000.	-673000.	-3411000.	-3369000.	-3165208.	76730.	275460.
ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	972000.	1033884.	1097460.	1192420.
CUMULATIVE GROSS PROFITS	-496000.	-1626000.	-2828000.	-3851000.	-4524000.	-7935000.	11304000.	14469208.	14392478.	14117018.
BASE FOR INTEREST EXP.	496000.	1626000.	2828000.	3851000.	4524000.	7935000.	12276000.	15503092.	15489938.	15309438.
INTEREST EXPENSE	49600.	162600.	282800.	385100.	452400.	793500.	1227600.	1550309.	1548994.	1530944.
INCOME BEFORE TAXES	-545600.	-1292600.	-1484800.	-1408100.	-1125400.	-4204500.	-4596600.	-4715517.	-1472264.	-1255484.
TAXES	-261888.	-620448.	-712704.	-675888.	-540192.	-2018160.	-2206368.	-2263448.	-706687.	-602632.
NET INCOME AFTER TAXES	-283712.	-672152.	-772096.	-732212.	-585208.	-2186340.	-2390232.	-2452069.	-765577.	-652852.
NET CHANGE IN INVEST.	0.	0.	0.	0.	0.	0.	972000.	61884.	63576.	94960.
ANNUAL CASH FLOW	-283712.	-672152.	-772096.	-732212.	-585208.	-2186340.	-3362232.	-2513953.	-829153.	-747812.
CUMULATIVE CASH FLOW	-283712.	-955864.	-1727960.	-2460172.	-3045380.	-5231720.	-8593952.	-11107905.	-11937058.	-12684870.
RETURN ON INVESTMENT (PCT)	.00	.00	.00	.00	.00	.00	-245.91	-237.17	-69.76	-54.75
NET INCOME TO SALES (PCT)	.00	.00	.00	.00	.00	.00	.00	-1226.03	-153.12	-65.29

O P E R A T I N G E X P E N S E

	75	76	77	78	79	80	81	82	83	84
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	7.66	7.66	7.66
UNITS MANUFACTURED (UNITS)	0.	0.	0.	0.	0.	0.	0.	12000.	30000.	60000.
COST OF GOODS MFG.	0.	0.	0.	0.	0.	0.	0.	91920.	229800.	459600.
AVERAGE INVENTORY***	0.	0.	0.	0.	0.	0.	0.	18384.	45960.	91920.
R AND D EXPENSE	496000.	1130000.	1202000.	1023000.	673000.	3411000.	3261000.	3128000.	0.	0.
ENGINEERING EXPENSE	0.	0.	0.	0.	0.	0.	0.	4596.	11490.	22980.
SELLING EXPENSE	0.	0.	0.	0.	0.	0.	0.	10000.	25000.	50000.
ADMINISTRATION EXPENSES	0.	0.	0.	0.	0.	0.	0.	9192.	22980.	45960.
DEPRECIATION EXPENSES**	0.	0.	0.	0.	0.	0.	108000.	121500.	134000.	146000.
TOTAL OPERATING EXPENSES	496000.	1130000.	1202000.	1023000.	673000.	3411000.	3369000.	3365208.	423270.	724540.

I N V E S T M E N T

	75	76	77	78	79	80	81	82	83	84
RECEIVABLES (AVG)	0.	0.	0.	0.	0.	0.	0.	40000.	100000.	200000.
INVENTORIES (AVG)	0.	0.	0.	0.	0.	0.	0.	18384.	45960.	91920.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	135000.	125000.	120000.
CUMULATIVE PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	1215000.	1340000.	1460000.
ANNUAL DEPRECIATION	0.	0.	0.	0.	0.	0.	108000.	121500.	134000.	146000.
CUMULATIVE DEPRECIATION	0.	0.	0.	0.	0.	0.	108000.	229500.	363500.	509500.
NET PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	972000.	985500.	976500.	950500.
OTHER INVESTMENT****	0.	0.	0.	0.	0.	0.	0.	10000.	25000.	50000.
NET ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	972000.	1033884.	1097460.	1192420.

PRESENT VALUE OF ANNUAL CASH FLOW -6665172.

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.
** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.
*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS
**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-2A. Case A – SAW Devices Cash Flow Analysis

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SAW DEVICES CASE A
CASH FLOW ANALYSIS

	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	300000.	400000.	500000.	500000.	500000.	500000.	500000.	500000.	0.	0.
MARKET SHARE (PCT)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	.00	.00
UNITS SOLD (UNITS)	150000.	200000.	250000.	250000.	250000.	250000.	250000.	250000.	0.	0.
UNIT PRICE	20.	20.	20.	20.	20.	20.	20.	20.	0.	0.
SALES	3000000.	4000000.	5000000.	5000000.	5000000.	5000000.	5000000.	5000000.	0.	0.
OPERATING EXPENSES	1893620.	2484160.	3062700.	3062700.	3062700.	3062700.	3062700.	3062700.	0.	0.
GROSS PROFITS	1106380.	1515840.	1937300.	1937300.	1937300.	1937300.	1937300.	1937300.	0.	0.
ANNUAL INVESTMENT	1638260.	1830190.	1902100.	1732100.	1562100.	1392100.	2302100.	2267100.	0.	0.
CUMULATIVE GROSS PROFITS	13010638.	11494798.	-9557498.	-7620198.	-5682898.	-3745598.	-1808298.	129002.	0.	0.
BASE FOR INTEREST EXP.	14648898.	13324978.	11459598.	9352298.	7244998.	5137698.	4110398.	2138098.	0.	0.
INTEREST EXPENSE	1464890.	1332498.	1145960.	935230.	724500.	513770.	411040.	213810.	0.	0.
INCOME BEFORE TAXES	-358510.	183342.	791340.	1002070.	1212800.	1423530.	1526260.	1723490.	0.	0.
TAXES	-172085.	88004.	379843.	480994.	582144.	683294.	732605.	827275.	0.	0.
NET INCOME AFTER TAXES	-186425.	95338.	411497.	521077.	630656.	740236.	793655.	896215.	0.	0.
NET CHANGE IN INVEST.	445840.	191920.	71920.	-170000.	-170000.	-170000.	910000.	-35000.	0.	0.
ANNUAL CASH FLOW	-632265.	-96582.	339577.	691077.	800656.	910236.	-116345.	931215.	0.	0.
CUMULATIVE CASH FLOW	-13317135.	-13413717.	-13074140.	-12383063.	-11582407.	-10672172.	-10788516.	-9857301.	0.	0.
RETURN ON INVESTMENT(PCT)	-11.38	5.21	21.63	30.08	40.37	53.17	34.48	39.53	.00	.00
NET INCOME TO SALES (PCT)	-6.21	2.38	8.23	10.42	12.61	14.80	15.87	17.92	.00	.00

OPERATING EXPENSE

	85	86	87	88	89	90	91	92	93	94
UNIT MANUFACTURING COST	7.66	7.66	7.66	7.66	7.66	7.66	7.66	7.66	.00	.00
UNITS MANUFACTURED(UNITS)	180000.	240000.	300000.	300000.	300000.	300000.	300000.	300000.	0.	0.
COST OF GOODS MFG.	1378800.	1838400.	2298000.	2298000.	2298000.	2298000.	2298000.	2298000.	0.	0.
AVERAGE INVENTORY***	275760.	367680.	459600.	459600.	459600.	459600.	459600.	459600.	0.	0.
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ENGINEERING EXPENSE	68940.	91920.	114900.	114900.	114900.	114900.	114900.	114900.	0.	0.
SELLING EXPENSE	150000.	200000.	250000.	250000.	250000.	250000.	250000.	250000.	0.	0.
ADMINISTRATION EXPENSES	137880.	183840.	229800.	229800.	229800.	229800.	229800.	229800.	0.	0.
DEPRECIATION EXPENSES**	158000.	170000.	170000.	170000.	170000.	170000.	170000.	170000.	0.	0.
TOTAL OPERATING EXPENSES	1893620.	2484160.	3062700.	3062700.	3062700.	3062700.	3062700.	3062700.	0.	0.

INVESTMENT

	85	86	87	88	89	90	91	92	93	94
RECEIVABLES (AVG)	600000.	800000.	1000000.	1000000.	1000000.	1000000.	1000000.	1000000.	0.	0.
INVENTORIES (AVG)	275760.	367680.	459600.	459600.	459600.	459600.	459600.	459600.	0.	0.
ANNUAL PLANT AND EQUIP.	120000.	120000.	0.	0.	0.	0.	1080000.	135000.	0.	0.
CUMULATIVE PLANT + EQUIP.	1580000.	1700000.	1700000.	1700000.	1700000.	1700000.	2780000.	2915000.	0.	0.
ANNUAL DEPRECIATION	158000.	170000.	170000.	170000.	170000.	170000.	170000.	170000.	0.	0.
CUMULATIVE DEPRECIATION	667500.	837500.	1007500.	1177500.	1347500.	1517500.	1687500.	1857500.	0.	0.
NET PLANT + EQUIP.	912500.	862500.	692500.	522500.	352500.	182500.	1092500.	1057500.	0.	0.
OTHER INVESTMENT****	150000.	200000.	250000.	250000.	250000.	250000.	250000.	250000.	0.	0.
NET ANNUAL INVESTMENT	1638260.	1830190.	1902100.	1732100.	1562100.	1392100.	2302100.	2267100.	0.	0.
PRESENT VALUE OF ANNUAL CASH FLOW			-6665172.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.
** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.
*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS
**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-2B. Case A - SAW Devices Cash Flow Analysis

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S A W D E V I C E S C A S E B

INPUT VALUES

INPUTS:	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	2000.	3000.	20000.	50000.	100000.
MARKET SHARE (PCT)	0.	0.	0.	0.	0.	0.	0.	50.	50.	50.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	20.	20.	20.
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	7.66	7.66	7.66
R AND D EXPENSE	0.	319000.	398000.	279000.	246000.	149000.	368000.	2807000.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	135000.	125000.	120000.

INPUTS:	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	300000.	400000.	500000.	500000.	500000.	500000.	500000.	500000.	0.	0.
MARKET SHARE (PCT)	50.	50.	50.	50.	50.	50.	50.	50.	0.	0.
UNIT PRICE	20.	20.	20.	20.	20.	20.	20.	20.	0.	0.
UNIT MANUFACTURING COST	7.66	7.66	7.66	7.66	7.66	7.66	7.66	7.66	.00	.00
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ANNUAL PLANT AND EQUIP.	120000.	120000.	0.	0.	0.	0.	1080000.	135000.	0.	0.

PARAMETRIC PERCENTAGES:

PARAMETER	IDENTIFIER	VALUE	PARAMETER	IDENTIFIER	VALUE
INTEREST RATE	P11	10.00	UNITS MANUFACTURED PCT.	P21	120.00
AVERAGE INVENTORY PCT.	P23	20.00	ENGINEERING EXPENSE PCT.	P26	5.00
SELLING EXPENSE PCT.	P27	5.00	ADMINISTRATION EXPENSE PCT	P28	10.00
RECEIVABLES PCT.	P31	20.00	DEPRECIATION PERIOD(YRS)	P35	10.00
OTHER INVESTMENT PCT.	P38	5.00			

PERCENTAGE OF BASELINE USED INPUTS	IDENTIFIER	PCT	ADD/SUB FROM BASELINE INPUTS IDENTIFIER	VALUE
TOTAL MARKET	X1	100	A1	0.
MARKET SHARE	X2	100	A2	0.
UNIT PRICE	X3	100	A3	.00
UNIT MANUFACTURING COST	X4	100	A4	0.
R AND D EXPENSE	X5	100	A5	0.
ANNUAL PLANT AND EQUIP.	X6	100	A6	0.

Figure IV-3. Case B - SAW Devices Input Values

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SAW DEVICES CASE B
CASH FLOW ANALYSIS

	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	2000.	3000.	20000.	50000.	100000.
MARKET SHARE (PCT)	.00	.00	.00	.00	.00	.00	.00	50.00	50.00	50.00
UNITS SOLD (UNITS)	0.	0.	0.	0.	0.	0.	0.	10000.	25000.	50000.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	20.	20.	20.
SALES	0.	0.	0.	0.	0.	0.	0.	200000.	500000.	1000000.
OPERATING EXPENSES	0.	319000.	398000.	279000.	246000.	149000.	476000.	3044208.	423270.	724540.
GROSS PROFITS	0.	-319000.	-398000.	-279000.	-246000.	-149000.	-476000.	-2844208.	76730.	275460.
ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	972000.	1033884.	1097460.	1192420.
CUMULATIVE GROSS PROFITS	0.	-319000.	-717000.	-996000.	-1242000.	-1391000.	-1867000.	-4711208.	-4634478.	-4359018.
BASE FOR INTEREST EXP.	0.	319000.	717000.	996000.	1242000.	1391000.	2839000.	5745092.	5731938.	5551438.
INTEREST EXPENSE	0.	31900.	71700.	99600.	124200.	139100.	283900.	574509.	573194.	555144.
INCOME BEFORE TAXES	0.	-350900.	-469700.	-378600.	-370200.	-288100.	-759900.	-3418717.	-496464.	-279684.
TAXES	0.	-168432.	-225456.	-181728.	-177696.	-138288.	-364752.	-1640984.	-238303.	-134248.
NET INCOME AFTER TAXES	0.	-182468.	-244244.	-196872.	-192504.	-149812.	-395148.	-1777733.	-258161.	-145436.
NET CHANGE IN INVEST.	0.	0.	0.	0.	0.	0.	972000.	61884.	63576.	94960.
ANNUAL CASH FLOW	0.	-182468.	-244244.	-196872.	-192504.	-149812.	-1367148.	-1839617.	-321737.	-240396.
CUMULATIVE CASH FLOW	0.	-182468.	-426712.	-623584.	-816088.	-965900.	-2333048.	-4172665.	-4494402.	-4734798.
RETURN ON INVESTMENT(PCT)	.00	.00	.00	.00	.00	.00	-40.65	-171.95	-23.52	-12.20
NET INCOME TO SALES (PCT)	.00	.00	.00	.00	.00	.00	.00	-888.87	-51.63	-14.54
OPERATING EXPENSE										
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	7.66	7.66	7.66
UNITS MANUFACTURED(UNITS)	0.	0.	0.	0.	0.	0.	0.	12000.	30000.	60000.
COST OF GOODS MFG.	0.	0.	0.	0.	0.	0.	0.	91920.	229800.	459600.
AVERAGE INVENTORY***	0.	0.	0.	0.	0.	0.	0.	18384.	45960.	91920.
R AND D EXPENSE	0.	319000.	398000.	279000.	246000.	149000.	368000.	2807000.	0.	0.
ENGINEERING EXPENSE	0.	0.	0.	0.	0.	0.	0.	4596.	11490.	22980.
SELLING EXPENSE	0.	0.	0.	0.	0.	0.	0.	10000.	25000.	50000.
ADMINISTRATION EXPENSES	0.	0.	0.	0.	0.	0.	0.	9192.	22980.	45960.
DEPRECIATION EXPENSES**	0.	0.	0.	0.	0.	0.	108000.	121500.	134000.	146000.
TOTAL OPERATING EXPENSES	0.	319000.	398000.	279000.	246000.	149000.	476000.	3044208.	423270.	724540.
INVESTMENT										
RECEIVABLES (AVG)	0.	0.	0.	0.	0.	0.	0.	40000.	100000.	200000.
INVENTORIES (AVG)	0.	0.	0.	0.	0.	0.	0.	18384.	45960.	91920.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	135000.	125000.	120000.
CUMULATIVE PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	1215000.	1340000.	1460000.
ANNUAL DEPRECIATION	0.	0.	0.	0.	0.	0.	108000.	121500.	134000.	146000.
CUMULATIVE DEPRECIATION	0.	0.	0.	0.	0.	0.	108000.	229500.	363500.	509500.
NET PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	972000.	985500.	976500.	950500.
OTHER INVESTMENT****	0.	0.	0.	0.	0.	0.	0.	10000.	25000.	50000.
NET ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	972000.	1033884.	1097460.	1192420.
PRESENT VALUE OF ANNUAL CASH FLOW			-733275.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.
** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.
*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS
**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-4A. Case B - SAW Devices Cash Flow Analysis

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SAW DEVICES CASE B
CASH FLOW ANALYSIS

	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	300000.	400000.	500000.	500000.	500000.	500000.	500000.	500000.	0.	0.
MARKET SHARE (PCT)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	60.00	.00	.00
UNITS SOLD (UNITS)	150000.	200000.	250000.	250000.	250000.	250000.	250000.	250000.	0.	0.
UNIT PRICE	20.	20.	20.	20.	20.	20.	20.	20.	0.	0.
SALES	3000000.	4000000.	5000000.	5000000.	5000000.	5000000.	5000000.	5000000.	0.	0.
OPERATING EXPENSES	1893620.	2484160.	3062700.	3062700.	3062700.	3062700.	3062700.	3062700.	0.	0.
GROSS PROFITS	1106380.	1515840.	1937300.	1937300.	1937300.	1937300.	1937300.	1937300.	0.	0.
ANNUAL INVESTMENT	1638260.	1830180.	1902100.	1732100.	1562100.	1392100.	2302100.	2267100.	0.	0.
CUMULATIVE GROSS PROFITS	-3252638.	-1736798.	200502.	2137802.	4075102.	6012402.	7949702.	9887002.	0.	0.
BASE FOR INTEREST EXP.	4890898.	3566978.	1701598.	0.	0.	0.	0.	0.	0.	0.
INTEREST EXPENSE	489090.	356698.	170160.	0.	0.	0.	0.	0.	0.	0.
INCOME BEFORE TAXES	617290.	1159142.	1767140.	1937300.	1937300.	1937300.	1937300.	1937300.	0.	0.
TAXES	296299.	556388.	848227.	929904.	929904.	929904.	929904.	929904.	0.	0.
NET INCOME AFTER TAXES	320991.	602754.	918913.	1007396.	1007396.	1007396.	1007396.	1007396.	0.	0.
NET CHANGE IN INVEST.	445840.	191920.	71920.	-170000.	-170000.	-170000.	910000.	-35000.	0.	0.
ANNUAL CASH FLOW	-124849.	410834.	846993.	1177396.	1177396.	1177396.	97396.	1042396.	0.	0.
CUMULATIVE CASH FLOW	-4859647.	-4448813.	-3601820.	-2424424.	-1247028.	-69632.	27764.	1070160.	0.	0.
RETURN ON INVESTMENT (PCT)	19.59	32.93	48.31	58.16	64.49	72.37	43.76	44.44	.00	.00
NET INCOME TO SALES (PCT)	10.70	15.07	18.38	20.15	20.15	20.15	20.15	20.15	.00	.00

OPERATING EXPENSE

	85	86	87	88	89	90	91	92	93	94
UNIT MANUFACTURING COST	7.66	7.66	7.66	7.66	7.66	7.66	7.66	7.66	.00	.00
UNITS MANUFACTURED (UNITS)	180000.	240000.	300000.	300000.	300000.	300000.	300000.	300000.	0.	0.
COST OF GOODS MFG.	1378800.	1838400.	2298000.	2298000.	2298000.	2298000.	2298000.	2298000.	0.	0.
AVERAGE INVENTORY***	275760.	367680.	459600.	459600.	459600.	459600.	459600.	459600.	0.	0.
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ENGINEERING EXPENSE	68940.	91920.	114900.	114900.	114900.	114900.	114900.	114900.	0.	0.
SELLING EXPENSE	150000.	200000.	250000.	250000.	250000.	250000.	250000.	250000.	0.	0.
ADMINISTRATION EXPENSES	137880.	183840.	229800.	229800.	229800.	229800.	229800.	229800.	0.	0.
DEPRECIATION EXPENSES**	158000.	170000.	170000.	170000.	170000.	170000.	170000.	170000.	0.	0.
TOTAL OPERATING EXPENSES	1893620.	2484160.	3062700.	3062700.	3062700.	3062700.	3062700.	3062700.	0.	0.

INVESTMENT

	85	86	87	88	89	90	91	92	93	94
RECEIVABLES (AVG)	600000.	800000.	1000000.	1000000.	1000000.	1000000.	1000000.	1000000.	0.	0.
INVENTORIES (AVG)	275760.	367680.	459600.	459600.	459600.	459600.	459600.	459600.	0.	0.
ANNUAL PLANT AND EQUIP.	120000.	120000.	0.	0.	0.	0.	1080000.	135000.	0.	0.
CUMULATIVE PLANT + EQUIP.	1580000.	1700000.	1700000.	1700000.	1700000.	1700000.	2780000.	2915000.	0.	0.
ANNUAL DEPRECIATION	158000.	170000.	170000.	170000.	170000.	170000.	170000.	170000.	0.	0.
CUMULATIVE DEPRECIATION	667500.	837500.	1007500.	1177500.	1347500.	1517500.	1687500.	1857500.	0.	0.
NET PLANT + EQUIP.	912500.	862500.	692500.	522500.	352500.	182500.	1092500.	1057500.	0.	0.
OTHER INVESTMENT****	150000.	200000.	250000.	250000.	250000.	250000.	250000.	250000.	0.	0.
NET ANNUAL INVESTMENT	1638260.	1830180.	1902100.	1732100.	1562100.	1392100.	2302100.	2267100.	0.	0.

PRESENT VALUE OF ANNUAL CASH FLOW -733275.

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.
** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.
*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS
**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-4B. Case B - SAW Devices Cash Flow Analysis

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SAW DEVICES CASE C
INPUT VALUES

INPUTS:	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	2000.	3000.	20000.	50000.	100000.
MARKET SHARE (PCT)	0.	0.	0.	0.	0.	0.	0.	50.	50.	50.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	30.	30.	30.
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	7.66	7.66	7.66
R AND D EXPENSE	0.	319000.	398000.	279000.	246000.	149000.	368000.	2807000.	0.	0.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	135000.	125000.	120000.

INPUTS:	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	300000.	400000.	500000.	500000.	500000.	500000.	500000.	500000.	0.	0.
MARKET SHARE (PCT)	50.	50.	50.	50.	50.	50.	50.	50.	0.	0.
UNIT PRICE	30.	30.	30.	30.	30.	30.	30.	30.	0.	0.
UNIT MANUFACTURING COST	7.66	7.66	7.66	7.66	7.66	7.66	7.66	7.66	.00	.00
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ANNUAL PLANT AND EQUIP.	120000.	120000.	0.	0.	0.	0.	1080000.	135000.	0.	0.

PARAMETRIC PERCENTAGES:

PARAMETER	IDENTIFIER	VALUE	PARAMETER	IDENTIFIER	VALUE
INTEREST RATE	P11	10.00	UNITS MANUFACTURED PCT.	P21	120.00
AVERAGE INVENTORY PCT.	P23	20.00	ENGINEERING EXPENSE PCT.	P26	5.00
SELLING EXPENSE PCT.	P27	5.00	ADMINISTRATION EXPENSE PCT	P28	10.00
RECEIVABLES PCT.	P31	20.00	DEPRECIATION PERIOD(YRS)	P35	10.00
OTHER INVESTMENT PCT.	P38	5.00			

PERCENTAGE OF BASELINE USED INPUTS	IDENTIFIER	PCT	ADD/SUB FROM BASELINE INPUTS IDENTIFIER	VALUE
TOTAL MARKET	X1	100	A1	0.
MARKET SHARE	X2	100	A2	0.
UNIT PRICE	X3	100	A3	.00
UNIT MANUFACTURING COST	X4	100	A4	0.
R AND D EXPENSE	X5	100	A5	0.
ANNUAL PLANT AND EQUIP.	X6	100	A6	0.

Figure IV-5. Case C – SAW Devices Input Values

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S A W D E V I C E S   C A S E C
C A S H F L O W A N A L Y S I S

	75	76	77	78	79	80	81	82	83	84
TOTAL MARKET (UNITS)	0.	0.	0.	0.	0.	2000.	3000.	20000.	60000.	100000.
MARKET SHARE (PCT)	.00	.00	.00	.00	.00	.00	.00	50.00	50.00	50.00
UNITS SOLD (UNITS)	0.	0.	0.	0.	0.	0.	0.	10000.	25000.	50000.
UNIT PRICE	0.	0.	0.	0.	0.	0.	0.	30.	30.	30.
SALES	0.	0.	0.	0.	0.	0.	0.	300000.	750000.	1500000.
OPERATING EXPENSES	0.	319000.	398000.	279000.	246000.	149000.	476000.	3049208.	435770.	749540.
GROSS PROFITS	0.	-319000.	-398000.	-279000.	-246000.	-149000.	-476000.	-2749208.	314230.	750460.
ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	972000.	1048884.	1134960.	1267420.
CUMULATIVE GROSS PROFITS	0.	-319000.	-717000.	-996000.	-1242000.	-1391000.	-1867000.	-4616208.	-4301978.	-3551518.
BASE FOR INTEREST EXP.	0.	319000.	717000.	996000.	1242000.	1391000.	2839000.	5665092.	5436938.	4818938.
INTEREST EXPENSE	0.	31900.	71700.	99600.	124200.	139100.	283900.	566509.	543694.	481894.
INCOME BEFORE TAXES	0.	-350900.	-469700.	-378600.	-370200.	-288100.	-759900.	-3315717.	-229464.	268566.
TAXES	0.	-168432.	-225456.	-181728.	-177696.	-138288.	-364752.	-1591544.	-110143.	128912.
NET INCOME AFTER TAXES	0.	-182468.	-244244.	-196872.	-192504.	-149812.	-395148.	-1724173.	-119321.	139654.
NET CHANGE IN INVEST.	0.	0.	0.	0.	0.	0.	972000.	76884.	86076.	132460.
ANNUAL CASH FLOW	0.	-182468.	-244244.	-196872.	-192504.	-149812.	-1367148.	-1801057.	-205397.	7194.
CUMULATIVE CASH FLOW	0.	-182468.	-426712.	-623584.	-816088.	-965900.	-2333048.	-4134105.	-4339502.	-4332308.
RETURN ON INVESTMENT(PCT)	.00	.00	.00	.00	.00	.00	-40.65	-164.38	-10.51	11.02
NET INCOME TO SALES (PCT)	.00	.00	.00	.00	.00	.00	.00	-574.72	-15.91	9.31

O P E R A T I N G E X P E N S E

	75	76	77	78	79	80	81	82	83	84
UNIT MANUFACTURING COST	.00	.00	.00	.00	.00	.00	.00	7.66	7.66	7.66
UNITS MANUFACTURED(UNITS)	0.	0.	0.	0.	0.	0.	0.	12000.	30000.	60000.
COST OF GOODS MFG.	0.	0.	0.	0.	0.	0.	0.	91920.	229800.	459600.
AVERAGE INVENTORY***	0.	0.	0.	0.	0.	0.	0.	18384.	45960.	91920.
R AND D EXPENSE	0.	319000.	398000.	279000.	246000.	149000.	368000.	2807000.	0.	0.
ENGINEERING EXPENSE	0.	0.	0.	0.	0.	0.	0.	4596.	11490.	22980.
SELLING EXPENSE	0.	0.	0.	0.	0.	0.	0.	15000.	37500.	75000.
ADMINISTRATION EXPENSES	0.	0.	0.	0.	0.	0.	0.	9192.	22980.	45960.
DEPRECIATION EXPENSES**	0.	0.	0.	0.	0.	0.	108000.	121500.	134000.	146000.
TOTAL OPERATING EXPENSES	0.	319000.	398000.	279000.	246000.	149000.	476000.	3049208.	435770.	749540.

I N V E S T M E N T

	75	76	77	78	79	80	81	82	83	84
RECEIVABLES (AVG)	0.	0.	0.	0.	0.	0.	0.	60000.	150000.	300000.
INVENTORIES (AVG)	0.	0.	0.	0.	0.	0.	0.	18384.	45960.	91920.
ANNUAL PLANT AND EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	135000.	125000.	120000.
CUMULATIVE PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	1080000.	1215000.	1340000.	1460000.
ANNUAL DEPRECIATION	0.	0.	0.	0.	0.	0.	108000.	121500.	134000.	146000.
CUMULATIVE DEPRECIATION	0.	0.	0.	0.	0.	0.	108000.	229500.	363500.	509500.
NET PLANT + EQUIP.	0.	0.	0.	0.	0.	0.	972000.	985500.	976500.	950500.
OTHER INVESTMENT****	0.	0.	0.	0.	0.	0.	0.	15000.	37500.	75000.
NET ANNUAL INVESTMENT	0.	0.	0.	0.	0.	0.	972000.	1048884.	1134960.	1267420.
PRESENT VALUE OF ANNUAL CASH FLOW			2062609.							

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.
** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.
*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS
**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-6A. Case C - SAW Devices Cash Flow Analysis

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SAW DEVICES CASE C
CASH FLOW ANALYSIS

	85	86	87	88	89	90	91	92	93	94
TOTAL MARKET (UNITS)	300000.	400000.	500000.	500000.	500000.	500000.	500000.	500000.	0.	0.
MARKET SHARE (PCT)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	.00	.00
UNITS SOLD (UNITS)	150000.	200000.	250000.	250000.	250000.	250000.	250000.	250000.	0.	0.
UNIT PRICE	30.	30.	30.	30.	30.	30.	30.	30.	0.	0.
SALES	4500000.	6000000.	7500000.	7500000.	7500000.	7500000.	7500000.	7500000.	0.	0.
OPERATING EXPENSES	1968620.	2584160.	3187700.	3187700.	3187700.	3187700.	3187700.	3187700.	0.	0.
GROSS PROFITS	2531380.	3415840.	4312300.	4312300.	4312300.	4312300.	4312300.	4312300.	0.	0.
ANNUAL INVESTMENT	1863260.	2130180.	2277100.	2107100.	1937100.	1767100.	2677100.	2642100.	0.	0.
CUMULATIVE GROSS PROFITS	-1020138.	2395702.	6708002.	11020302.	15332602.	19644902.	23957202.	28269502.	0.	0.
BASE FOR INTEREST EXP.	2883398.	0.	0.	0.	0.	0.	0.	0.	0.	0.
INTEREST EXPENSE	288340.	0.	0.	0.	0.	0.	0.	0.	0.	0.
INCOME BEFORE TAXES	2243040.	3415840.	4312300.	4312300.	4312300.	4312300.	4312300.	4312300.	0.	0.
TAXES	1076659.	1639603.	2069904.	2069904.	2069904.	2069904.	2069904.	2069904.	0.	0.
NET INCOME AFTER TAXES	1166381.	1776237.	2242396.	2242396.	2242396.	2242396.	2242396.	2242396.	0.	0.
NET CHANGE IN INVEST.	595840.	266920.	146920.	-170000.	-170000.	-170000.	910000.	-35000.	0.	0.
ANNUAL CASH FLOW	570541.	1509317.	2095476.	2412396.	2412396.	2412396.	1332396.	2277396.	0.	0.
CUMULATIVE CASH FLOW	-3761767.	-2252450.	-156974.	2255422.	4667818.	7080214.	8412610.	10690006.	0.	0.
RETURN ON INVESTMENT(PCT)	62.60	83.38	98.48	106.42	115.76	126.90	83.76	84.87	.00	.00
NET INCOME TO SALES (PCT)	25.92	29.60	29.90	29.90	29.90	29.90	29.90	29.90	.00	.00

OPERATING EXPENSE

	85	86	87	88	89	90	91	92	93	94
UNIT MANUFACTURING COST	7.66	7.66	7.66	7.66	7.66	7.66	7.66	7.66	.00	.00
UNITS MANUFACTURED(UNITS)	180000.	240000.	300000.	300000.	300000.	300000.	300000.	300000.	0.	0.
COST OF GOODS MFG.	1378800.	1838400.	2298000.	2298000.	2298000.	2298000.	2298000.	2298000.	0.	0.
AVERAGE INVENTORY***	275760.	367680.	459600.	459600.	459600.	459600.	459600.	459600.	0.	0.
R AND D EXPENSE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ENGINEERING EXPENSE	68940.	91920.	114900.	114900.	114900.	114900.	114900.	114900.	0.	0.
SELLING EXPENSE	225000.	300000.	375000.	375000.	375000.	375000.	375000.	375000.	0.	0.
ADMINISTRATION EXPENSES	137880.	183840.	229800.	229800.	229800.	229800.	229800.	229800.	0.	0.
DEPRECIATION EXPENSES**	158000.	170000.	170000.	170000.	170000.	170000.	170000.	170000.	0.	0.
TOTAL OPERATING EXPENSES	1968620.	2584160.	3187700.	3187700.	3187700.	3187700.	3187700.	3187700.	0.	0.

INVESTMENT

	85	86	87	88	89	90	91	92	93	94
RECEIVABLES (AVG)	900000.	1200000.	1500000.	1500000.	1500000.	1500000.	1500000.	1500000.	0.	0.
INVENTORIES (AVG)	275760.	367680.	459600.	459600.	459600.	459600.	459600.	459600.	0.	0.
ANNUAL PLANT AND EQUIP.	120000.	120000.	0.	0.	0.	0.	1080000.	135000.	0.	0.
CUMULATIVE PLANT + EQUIP.	1580000.	1700000.	1700000.	1700000.	1700000.	1700000.	2780000.	2915000.	0.	0.
ANNUAL DEPRECIATION	158000.	170000.	170000.	170000.	170000.	170000.	170000.	170000.	0.	0.
CUMULATIVE DEPRECIATION	667500.	837500.	1007500.	1177500.	1347500.	1517500.	1687500.	1857500.	0.	0.
NET PLANT + EQUIP.	912500.	862500.	692500.	522500.	352500.	182500.	1092500.	1057500.	0.	0.
OTHER INVESTMENT****	225000.	300000.	375000.	375000.	375000.	375000.	375000.	375000.	0.	0.
NET ANNUAL INVESTMENT	1863260.	2130180.	2277100.	2107100.	1937100.	1767100.	2677100.	2642100.	0.	0.
PRESENT VALUE OF ANNUAL CASH FLOW		2062609.								

* ASSUME TAX LOSS IS CREDITED AGAINST OTHER BUSINESS INCOME.
** THIS ITEM IS NORMALLY INCLUDED IN VARIOUS OVERHEAD ACCOUNTS.
*** INVENTORY DERIVATION IS HIGHLY SIMPLIFIED, BUT APPROXIMATES MORE COMPLEX METHODS
**** INCLUDES MISC. LIABILITIES SUCH AS ACCOUNTS PAYABLE, RESERVES, SUNDRY CREDITOR ITEMS

Figure IV-6B. Case C - SAW Devices Cash Flow Analysis

	CASE A	CASE B	CASE C
% NI/S (1992)	18%	20%	29%
% ROI (1992)	40%	44%	85%
PRESENT VALUE	-S6.7	-S0 7M	S2M
USER R&D COST	S14.3M	S4 6M	S5M
NASA R&D COST	–	S9 7M	S10M
UNIT PRICE	S20	S20	S30
BREAKEVEN POINT	> 20 YRS	16 YRS	13 YRS

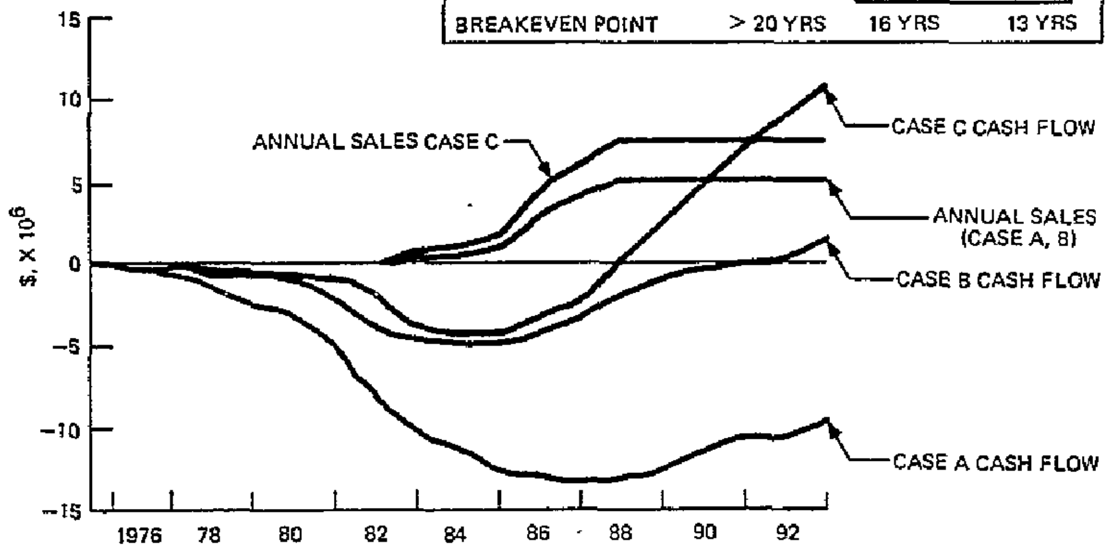

Figure IV-7. SAW Devices Cash Flow

SECTION V

MARKET ANALYSIS

V.1 INTRODUCTION

The market addressed is that for: 1) Surface Acoustic Wave (SAW) bandpass filters with center frequency above 10 GHz with a capability goal of 30 GHz; crystal wafer size, 1 mm x 2 mm x 1 mm thick; weight, 1 milligram, using spacegrown lithium niobate crystal; aluminum electrode pattern formed by x-ray lithography on one surface; interdigitated fingers of 750 A^{o} for 10 GHz and 250 A^{o} for 30 GHz. 2) SAW matched filter sets for linear-FM pulse generation/compression, frequencies in the range 10-30 GHz, compression ratios in the range 100-10,000, crystal wafer size 1 mm x 2 mm x 1 mm thick, weight 1 milligram.

Present technology is active in the 3 GHz range, where devices have been demonstrated as part of research programs. The concept for the business which would approach the market of interest is described in the following paragraphs:

V.1.1 ORGANIZATION

The Business is established as a product line under a product manager in the house of an existing manufacturer of microminiature electronic devices, who has the support of an appropriate SAW device research laboratory. The 250,000 SAW devices produced per year are marketed (either as circuit components, or incorporated into electronic equipment for sale) via the existing sales and distribution channels of the manufacturer.

V.1.2 FACILITIES AND EQUIPMENT

The Business provides its own crystals by growing them in a shuttle-supported crystal growing facility consisting of 5 processors. One extra processor is maintained as a backup.

Each processor is capable of growing boules of 3-4 cm diameter at a rate of 0.5 cm per hour. Annual production is 300-400 cm of high purity crystal boules per year, using one 7-day shuttle flight per year.

The boules are returned to earth and cut into wafers in a crystal cutting and polishing facility, which is equipped with optical quality cutting and polishing equipment.

At this same facility, the crystal wafers are cleaned with an ion beam scrubber (or back sputter equipment), and given a metalized coating and a resist coating.

Masks to be used for exposing patterns on the wafers are made in a shuttle-borne facility owned by the Business, which is capable of exposing 100-200 2 x 2 mm masks per week in orbit.

The mask preparation consists of polymerizing via electron beam, of a polymethylcrylate resist surface in a pattern determined by computerized mask cutting controls. The exposed masks are then developed and etched in a ground facility, to give a chromium-on-gold finger pattern on a silicon substrate. The single-chip masks are replicated with a step-and-repeat ground process to produce single masks containing up to 156 chip circuits.

The Business provides a ground facility for exposing masked crystal wafers to soft x-rays. The facility is capable of accurately positioning a 3-4 cm diameter mask over a crystal wafer of the same diameter, and exposing the crystals with an x-ray beam. Masks can be used for 500-1000 exposure cycles.

After x-ray exposure, the crystal wafers are developed and etched and cut into individual circuit chips at a ground facility. The chips are then mounted, packaged and tested as SAW devices. The throughput of this SAW device finishing facility is a quarter million devices per year.

V.1.3 INITIAL R&D

To reach production status, the Business has incurred a significant expense in research and development of space facilities for crystal growing, mask fabrication, and crystal exposure. This R&D expense amounts to $4.6 million spread over 7 years.

V.1.4 CONTINUING R&D (ENG'G DEV./ADVANCED ENG'G)

The Business maintains a continuing R&D program for product and facility development of 5% of sales, to assure a competitive product.

V.1.5 SPACE SHUTTLE SERVICES

Arrangements have been made with NASA for regular shuttle services for up-transport, on-orbit support and down-transport of its two types of facilities. On-orbit operating times are 7 days per flight. The procedures for using shuttle services were established during the R&D phase, and service charges, legal considerations, schedules, etc. have been agreed to and documented.

V.1.6 INVENTORIES AND RECEIVABLES

The Business produces relatively few product types in large quantities based on orders received, and limits its net inventory of 20% of sales. Receivables average 20% of sales.

V.2 PRODUCT BENEFITS

The Surface Acoustic Wave device will offer, in the 10-30 GHz range, a unit of small size and weight, which is easily reproducible, promises long life, requires no adjustments, and can handle multifunctions with high performance. These features will be of specific benefit to mobile and airborne communications and radar system manufacturers, as well as any others who will be manufacturing transmission/receiving equipment using the 10-30 GHz ranges.

V.3 COMPETITIVE PRODUCTS & COMPETITORS

There are other products which could be competitive with SAW devices in the 10-30 GHz range. The strip line filter has a low insertion loss, but is relatively large and has limited performance. Multi-cavity filters are large and expensive. Tapped coaxial cable pulse compressors are large, expensive and require ancillary weighting filters. The new SAW device advantages over the above items would be in lesser size, weight, and performance, in general, with lesser cost in some cases.

V.4 POTENTIAL ALTERNATIVES

The most serious alternative to bhe space-processed SAW device, apart from the devices mentioned in paragraph V.3, would be the identical device manufactured on the ground. This would presume that ground-based environmental problems could be surmounted and that the same or similar SAW device performance could be achieved without incurring a space-processing expense.

While the limits of ground processing have not been established, present knowledge suggests that the ground alternative is not easily achieved.

V.5 MARKET FORECAST

The market has been forecast for two SAW device products: 1) a relatively low-priced bandpass filter and 2) a relatively high priced pulse compressor. The bandpass filters are applicable to RF filtering in multichannel radars (as many as 50 filters per radar set), RF filtering in mobile radios (aircraft, taxis, police cars, service trucks, private radio telephone), data link stations (facsimile, teletype, video communication, satellite links). About 5-10 million RF filters are required per year for TV receivers now. Aggregating these possibilities, a figure of 500,000 SAW bandpass filters (10-30 GHz) is guessed as the demand by about 1987.

Pulse compressors are presently used in military radar (1 per radar set) and will probably be used in the future in military ground and airborne radars. A rough

estimate of demand for 10-30 GHz SAW devices for these applications is 3000 units per year by about 1985.

Applying a gradual build-up to these quantities gives a demand forecast as follows:

Year	BP Filter	Pulse Compressor	Year	BP Filter	Pulse Compressor
1980	2K	20	1986	400K	3K
1981	3K	20	1987	500K	3K
1982	20K	100	1988	500K	3K
1983	50K	500	1989	500K	3K
1984	100K	2K	1990	500K	3K
1985	300K	3K	1991	500K	3K

Figure V-1. U.S. Demand for 10-30 GHz SAW Devices (Units) 1980-1992

V.6 PRODUCT QUANTITIES/PRICING

Assuming that the unit price is attractive, relative to the size, weight and performance benefits of the new SAW devices, a market share of 50% of the demand is estimated (ref. paragraph V.6), giving a sales forecast in units as follows:

Year	BP Filters	Pulse Compressor	Year	BP Filter	Pulse Compressor
1980	0	0	1986	200K	1.5K
1981	0	0	1987	250K	1.5K
1982	10K	50	1988	250K	1.5K
1983	25K	250	1989	250K	1.5K
1984	50K	1K	1990	250K	1.5K
1985	150K	1.5K	1991	250K	1.5K

Figure V-2. Sales Forecast for 10-30 GHz SAW Devices (Units) 1980-1992

A price of $20 per unit for the bandpass filter and $350 per unit for the pulse compressor has been recommended for analysis purposes. No firm basis for establishing a unit price has been found as yet. For comparison, an equivalent of the bandpass filter would probably cost $200 in small quantities today.

Also bandpass filters of GHz frequencies but much higher power capacities presently sell for over $500. On the other hand, crystal resonator type band pass filters at MHz frequencies presently sell at $30-40 in small quantities and are used in large quantities in mobile equipment at less than $5 per unit.

V.7 PRODUCT LIFE CYCLE

The life cycle for the 10-30 GHz SAW device is highly conjectural, since the device itself is conceptual at best. Equipment manufacturers would be introduced to the product using R&D-phase samples. Product decline would be caused by discovery of a superior alternate of some kind, presently unknown. Using a 10 year maturity phase, the product life cycle would be about as follows:

Phase	From	To
Introduction	1977	1980
Growth	1980	1985
Maturity	1985	1995
Decline	1995	?
Exit	?	?

Figure V-3. Saw Device (10-30 GHz) Product Life Cycle

SECTION VI

COST/VALUE FOR PRODUCTION

This section presents the baseline production concept for producing Surface Acoustic Wave devices (10-30 GHz) along with the assumptions and key findings for the product venture. It must be remembered that all figures given here are conceptual only, and are subject to change upon further and more detailed investigation.

VI.1 FLIGHTS AND RESOURCES REQUIRED FOR PILOT PLANT AND FULL SCALE PRODUCTION

The surface acoustic wave device production process presents a sequence of ground-space-ground process steps, with two in-space process steps required, that of crystal growing, and master mask cutting. A throughput analysis, unit product cost breakdown, and rough breakdown of associated costs are given in the following paragraphs.

VI.1.1 ANALYSIS OF PRODUCT VOLUME AND TIME VS PAYLOAD CAPACITY AND TIME

The forecasted manufacturing volume (units sold) starts at 10,000 units in 1982 and climbs to a plateau of 250,000 units (half of total market) by 1987. This production level would require 15 boules of high quality crystal (4 cm diameter by 22 cm length) which would be produced in one 7-day shuttle flight, using 5 crystal-growing processors. Earlier production would be satisfied with a lesser number of processors aboard.

The mask fabrication process is based on cutting of a relatively few 2x2 mm masks in space, which would then be replicated on the ground using a step-and-repeat process. The number of master masks required is undetermined, but one shuttle flight per year is assumed, during which up to 156 masters with identical or varied circuit patterns could be cut.

Thus no problem is foreseen in terms of flight capabilities versus production volume. A throughput analysis for the space and ground process step is shown in Figure VI-1, for an annual throughput of 250,000 units.

VI.1.2 ANALYSIS OF PROCESSING SUPPORT REQUIREMENTS VS SHUTTLE/SPACELAB AVAILABLE RESOURCES

The crystal growing facility, of which up to 5 processors would be required, although not designed, is thought of as being similar to present ground-based crystal growing stations, with zero-G provisions. Crew attention would be required at each station to remove completed boules and start the process for growth of another boule, unless an arrangement could be established for growing much longer boules.

The apparatus would be self-contained, with appropriate process controls and provision for raw material replenishment, so that crew attention during the process would be minimized. An estimated 220 KWH per boule (5 KW x 44 hours) would be required, for a total 7-day flight energy requirement of 15 boules x 220 KWH = 3300 KWH/flight for a production level of 250,000 units per year.

VI.1.3 DETERMINATION OF NUMBER OF FLIGHTS FOR PILOT PLANT AND PRODUCTION

A baseline assumption of one flight per year for crystal growing and one flight per year for cutting of master masks has been used, relative to an annual production of 250,000 SAW devices per year. Production in early years would probably use the same number of flights per year, but with fewer crystal growing stations and shorter mask cutting process times. The estimate of throughput capability and product demand is very preliminary, but it would appear that considerable flexibility would exist to accommodate a wide variation in the estimates used. A demand for periodic cutting of different mask patterns (e.g. upon customer request) could cause the number of mask-cutting flights to be higher than the baseline single flight per year.

A. Crystal Growing/Cutting Process

Boule Growing (Space)

1.	Boule size			
	a) diameter	4 cm		
	b) length	22 cm		
2.	Pulling rate	0.5 cm/hr		
3.	Boule pulling time (22 cm 0.5 cm/hr)	44 hrs		
4.	Flight time (7 day mission)	156 hrs		
5.	Boules per station (156 hrs 44 hrs/boule = 3			
6.	No. of stations per flight		5	
7.	Boules per flight (5 stations x 3 boules/station)		15	
7a.	No. of flights per year		1	
7b.	No. of boules per year		15	
8.	Boule - centimeters per flight (15 x 22 cm)		330	
9.	Boule - centimeters per year			
	a) required		318	
	b) produced (330 x 1 flt)		330	

B. Boule Cutting (Ground)

10.	Cutting yield factor (.04 cm saw cut, .06 cm wafer)	60%
11.	Wafer thickness	0.06 cm
12.	Useful boule centimeters after cutting (318 cm x 60%)	191 cm
13.	No. of wafers after cutting (191 cm 0.06 cm)	3183
14.	Wafer yield factor (after inspection)	90%
15.	No. of wafers after inspection (3183 x 90%)	2864

C. Crystal Clean, Metalize, Resist Process (Ground)

1.	Yield factor	90%
2.	No. of wafers input per year	2864
3.	No. of wafers output per year (2864 x 90%)	2577
4.	Batch output	
	a) Wafers per batch	9
	b) Batches per hour	1

TO D.2

Figure VI-1. SAW Device Throughput Analysis Basis-250K Units Per Year

FROM C. 3

D. Mask and X-Ray Expose Process (Ground)

1. Yield factor (after inspection) 90% (recycle rejects)
2. No. of wafers input per year 2577 TO I. 4
3. No. of wafers output per year (2577 x 90%) 2319
4. Wafers mask/exposure rate (1 station) 20 per hr.
5. No. of stations 1 TO I. 3

E. SAW Device Finishing Process (Ground)
Developing

1. No. of wafers input per year 2319
2. Yield factor 90% (recycle rejects)
3. No. of wafers output per year (2319 x 90%) 2087
4. No. of operating positions 1
5. Output rate per day - up to 100 wafers per day
6. Output rate per hour - up to 12-15 wafers per hour
7. Percent operator attention 1 man, 100% applied, (20 days)

F. Etch and Clean

8. No. of wafers input per year 2087
9. Yield factor 90%
10. No. of wafers output per year (2087 x 90% 1878
11. No. of operating positions 1
12. Output rate per day - up to 400 wafers per day
13. Output rate per hour - up to 50 wafers per hour
14. Percent operator attention 1 man, 50% applied

G. Wafer Cut and Clean

15. No. of wafers input per year 1878
15a. Yield factor 90%
16. No. of chips per wafer (after cutting) 156 (may increase with thinner saw)
17. No. of saw cuts per wafer (gang saw) 2 (1 x-axis, 1 y-axis)
18. Saw cutting rate 0. 5 cm per minute
19. Cutting distance per wafer (4 cm x2) 8 cm
20. Cutting time per wafer (8 cm 0. 5 cm/min.) 16 minutes
21. No. of blades in saw 15
22. Wafers cut per day (required) (1603 250 days) 7 per day
23. No. of wafers per saw per day (capacity) (480 min/day 16 min) 30
24. No. of saws required (7 wafers req'd, 30 wafers per day capacity 1
25. Percent operator attention 1 man per saw, 100%
26. No. of chips output per year (1878 x 156 x 90%) 263, 671

Figure VI-1. SAW Device Throughput Analysis Basis-250K Units Per Year (cont'd)

TO H. 27

FROM G.26

H. Device Package and Test

27. No. of chips input 263,671
28. Yield factor 95%
29. No. of SAW devices output per year (263,671 x 95%) 250,487
30. Package and test rate per station 20 devices per hour
31. Operator hours per year req'd (263,671 20/hr) 13184 man hrs.
32. No. of operators required (13184 2000 hrs/operator) 7
33. No. of work stations (1 per operator) 7

I. Mask Fabrication (Space) (2x2 mm master mask)

1. No. of masks per year (capacity, 1 flight) up to 156
2. Mask cycles per mask (for replication) 1000
3. No. of mask stations (mask cutting) 1
4. No. of inspected masks req'd per year:
   - No. of wafer maskings per year (with replica mask) 2577
   - No. of replica masks req'd (2577 ÷ 1000) 3 → TO J.1 (assumes 1 replica mask type)
   - No. of step and repeat maskings per year (3 x 156) 468
   - No. of 2 x 2 mm masks req'd (468 ÷ 1000) 1 (assumes only one circuit type)
5. Mask yield factor 40-80%
6. No. of 2 x 2 mm masks needed to be fabricated
   - at 40% yield (1 ÷ .40) 3
   - at 80% yield (1 ÷ .80) 2
7. Cutting time per mask 1 hour
8. No. of mask cutting flights (156 masks per flight) 1 per year

FROM D.5

FROM D.2

J. Mask Replication (Ground) (156 2x2 mm circuits per mask)

1. No. of replicated masks required per year 3 (up to 156)
2. Circuits per mask 156
3. No. of step and repeat cycles per mask 156
4. Mask cutting time (156 cycles x 1 minute/cycle) 3 hours
5. Total cutting time for 3 masks (3x3 hrs) 9 hours

Figure VI-1. SAW Device Throughput Analysis Basis-250K Units Per Year (cont'd)

VI.1.4 DETERMINATION OF RESOURCES REQUIRED FOR PILOT PLANT AND PRODUCTION

A summary of the production resource requirements is shown in Figure VI-2. Plant and equipment requirements are roughly estimated as shown in Figures VI-3A and 3B. About 45 to 50 personnel might be required, as listed in Figure VI-4.

VI.2 ANALYSIS OF PRODUCTION COSTS

A breakdown of the manufacturing costs by process step for an annual production of 250,000 units is shown in Figure VI-5. A unit manufacturing cost of $7.66 for all years was used in the financial forecast.

VI.2.1 SHUTTLE/SPACELAB OPERATION COSTS AND RESOURCE COSTS

Space operations costs at an annual production level of 250,000 units are estimated at $681K for crystal growing and $392K for mask fabrication for a total of $1073K/yr. (Figure VI-5). Most of this amount ($461K + $282K = $743K) is for shuttle services charges. The basis for space service charges is given in Figures VI-6 and VI-7.

VI.2.2 DEFINITION OF ADDITIONAL NON-SPACE PROGRAM COSTS

The non-space process steps account for 44% of the annual production costs ($843K, $1916K). (Figure VI-5). The SAW device finishing process accounts for most of the ground costs. Because of the small quantity of production, all ground processes are assumed to be performed in available plant space.

VI.2.3 ANALYSIS OF TOTAL PRODUCTION COSTS

The objective for the SAW device in the bandpass filter application is to sell at the lowest feasible unit price and thus establish a significant market demand. The relatively small estimated demand, when coupled with a low unit price of $20 and a unit manufacturing cost of $7.66, requires a long pay-back period, even though the gross margin is acceptable (see Section IV). A lower unit manufacturing cost would lead to

Materials

Raw crystalline materials (lithium niobate, sapphire, etc.)

Services

Computer programming for mask generation and test results analysis
Space shuttle transportation of facilities and materials, plus shuttle support

Equipment

Commercial-type crystal-cutting saws,
Commercial-type polishing and lapping equipment
X-ray diffraction equipment
Electron-beam equipment (high resolution)
Optical test equipment

Facilities

Lithography and fine line etching laboratory (clean room)
Computer facility for SAW device analysis
Shuttle-borne crystal growing facilities
Shuttle-borne mastermask cutting facility
Crystal cleaning and developing facility

Special Manpower Skills

Optical specialists
RF circuit specialists (10-30 GHz)
Electron beam etching specialists (SEBM)
Crystal growth (high purity) specialists

Figure VI-2. SAW Devices Production Resource Requirement Summary

			250K units per year
Crystal Growing (Space)			
Need 5 processors for 1, 1-week flight per year			
Space processors		120K each	
6 processors req'd x 120K = $720K			$ 720K
(design avail. from R&D program)			
Boule cutting - 1 station, saw (ground)			20K
Clean, metalize resist (hood, bath, venting)			5K
Mask and x-ray expose - 1 station			10K
SAW Device Finishing			
Develop (hood, bath, venting)			5K
Etch and Clean (hood, vent, bath, ultrasonic cleaner)			5K
Package and Test (holders, cleaner, tester, bonder, sealer)			25K
Mask Cutting (Space) 1 station			900K
SEBM (modified)	300K		
Controls	300K		
Positioning/holding system	200K		
Structure, cables	100K		
	900K		
Mask Replication - 1 station			10K
			$1700K

Figure VI-3A. Estimate of Plant & Equipment for SAW Device Processing (Production) Equip. Life - 10 yrs.

c-2

	80	81	82	83	84	85	86	87	88	89	90	91	92
Crystal Growing	-	120K	120K	120K	120K	120K	120K					120K	120K
Boule Cutting		20K										20K	
Clean, Metalize, Resist		5K										5K	
Mask & X-Ray Expose		10K										10K	
SAW Finishing		15K	15K	5K								15K	15K
Mask Cutting		900K										900K	
Mask Replication		10K										10K	
Annual Total		1080K	135K	125K	120K	120K	120K	-	-	-	-	1080K	135K
Cum Total		1080K	1215K	1340K	1460K	1580K	1700K	1700K	1700K	1700K	1700K	2780K	2915K

Figure VI-3B. Plant & Equipment by Year

	Annual Amount (1992)	Rough Estimate of Number of Personnel
Sales (dollars)	$5M	
Sales (units)	250,000	
Engineering Expense	$0.14M	3
Selling Expense	0.25M	5
Administrative Expense	0.23M	7
Manufacturing Cost	$2.3M	30
Net Annual Investment	2.3M	
	Total	45

Figure VI-4. Approximate Resources for Operating Year 1992
SAW Device (Case B)

a quicker payback period for a given market size and would also allow a lower unit price, which would lead to a larger market. Thus the high cost areas of production need to be examined for possible improvement, specifically the crystal growing, mask fabrication and device finishing steps. Space charges are a large cost contributor (39%) and any improvement there would be significant.

VI.3 ANALYSIS OF COST

The baseline (Case B) financial forecast for SAW devices presents an unattractive venture, due to the long payback period required to recoup R&D expenses. There would be some flexibility in establishing the unit price; and market size, given a successful product, may prove to be larger than assumed. Increases of these estimates could provide a more attractive proposition.

VI.3.1 DERIVATION OF GROSS MARGIN

Gross margin, or the difference between unit manufacturing cost and selling price, for the baseline case is estimated at $20.00 - $7.66 = $12.34 per unit in all years.

Basis: 250,000 Bandpass Filters/Yr.

		Annual Cost	Unit Cost
Crystal Growing (space)			
Ground Operations Labor		100K	
Ground Operations Overhead (100% of labor)		100K	
Materials		20K	
Space Services (NASA)		461K	
	Subtotal	681K	2.72
Cut and Polish (ground)			
Boule Cutting (2715 wafers @ $1)		3K	
Wafer Clean and Polish (2715 wafers $ $10)		27K	
	Subtotal	30K	0.12
Wafer Clean, Metalize, Resist (ground)			
(2443 wafers @ $1)		3K	.012
Wafer X-Ray Expose (ground)			
(2199 wafers 20/hr x $20/hr)		3K	.012
Mask Fabrication (2 x 2 mm) (space)			
Ground Operations Labor		50K	
Overhead		50K	
Materials		10K	
Space Services (NASA)		282K	
	Subtotal	392K	1.57
Mask Replication (ground)			
Labor (60 hrs @ $8)		1K	
Overhead		1K	
Materials		1K	
	Subtotal	3K	.012
SAW Device Finishing (ground)			
Develop (1979 wafers @ $2.00)		4K	
Etch and Clean (1781 wafers @ $0.41)		9K	
Cut and Clean (1603 wafers @ $5.40)		9K	
Package and Test (263,157 chips @ $3.00)		790K	
	Subtotal	804K	3.216
GRAND TOTAL		$1916K	$7.66

Figure VI-5. Unit Manufacturing Cost

Basis: 250,000 BP filters/yr.

	Annual Charges
Up-Transport volume (1 flt/yr)	
(1.35^3 x \$13,760 x 1)	18.6K
Up-Transport weight (incl. raw material)	
(182 kg/sta x 5 sta x \$110)	100.1K
Energy	
(220 kWH/boules x 15 boules x \$40/kWH)	132.0K
Crew	
(1 mm hr/day x 7 days x 1 flt x \$6450/hr)	45.1K
Data Transport	
(none)	-
Data Processing	
(none)	-
Down Weight (1 flt/yr)	
(182 Kg x 5 sta x 1 flt x \$180/Kg)	163.8K
Ground Operations (Vol.)	
($1.35M^3$ x \$1280/M^3 x 1 flt)	1.7K
Ground Operations (complexity)	
(none)	-
Total Annual Charges	461.3K
Charges per SAW device (÷250K units) (Crystal Growing Step)	\$ 1.85

Figure VI-6. Calculation of SAW Devices Production Space Charges - Crystal Growing

Basis: 250,000 BP filters/yr.
156 masks (2 x 2 mm)/yr. for ground replication

	Annual Charges
Up-Transport Volume (1 flt/yr) ($0.6M^3$ x 1 station x 1 flt x $13,760/$M^3$)	8.3K
Up-Transport Weight (545 kg x $110/Kg 1 flt)	60.0K
Energy (156 cycles x 3.4 kW = 624 KWH, say 600 KWH x $40/KWH)	24.0K
Crew (2 mm hrs/day x 7 days = 14 hrs x $6450/hr)	90.3K
Data Transport (none)	-
Data Processing (none)	-
Down Weight (545 kg x $180/Kg x 1 flt)	98.1K
Ground Operations (Volume) ($0.6M^3$ x 1 flt x $1280/$M^3$)	.8K
Ground Operations (complexity) (none)	-
Total Annual Charges	$281.5K
Charge per mask (÷156)	$1840
Charge per SAW device (÷250,000)	$ 1.13

Figure VI-7. Calculation of SAW Device Production Space Charges - Mask Exposure

Gross margin allows for net profit and expenses other than shop cost, (i.e.: R&D, engineering, selling, administration, depreciation, and interest expenses and federal income taxes). This margin gives a net income to sales of 20% in 1992 (Case B).

IV.3.2 IDENTIFICATION OF SIGNIFICANT COST/VALUE ASSUMPTIONS

A key assumption in forecasting the business was that the use of the 10-30 GHz spectrum would open up sufficiently in the 1980's to create a significant demand for band pass filters (on the order of 500,000 units per year) in that period. This assumption rests, in turn, on the assumption that a transmitter capability will be developed for that spectrum, in the time period 1975-1982.

Other fundamental assumptions are that the crystal growing and mask cutting processes can be successfully conducted in space, and that the space environment is essential to those processes.

The R&D program assumes that no major difficulties will be encountered in proving the feasibility of crystal growing and mask cutting, and that a nominal number of flight tests will be required to establish process techniques, on which the production methods can be directly based.

The space charges used are based on the BUS Phase III model and are a major cost element in the financial forecast. Any changes in the basis for space charges will thus have a significant effect on the forecasted business viability.

VI.3.3 SENSITIVITY ANALYSIS

The "present value" of the product venture (discounted at 10%) has been used as a common measure for assessing the sensitivity of the venture to the estimates used for the various cost elements. Each of the 15 parameters used in the cash flow analysis was varied $\pm$ 10%, and the financial forecast was calculated for each case, a total of 30 projections. The resultant present value in each case was then compared

with the baseline case (Case B) present value, giving the delta low (-10%) and delta high (+10%) figures as shown in Figure VI-8. The parameters with the largest changes in present value for a 10% change in estimate are thus of most interest. The high impact parameters are plotted in Figure VI-9. Unit price, unit manufacturing cost, market share and R&D program cost show high sensitivity, so that the estimate for these items warrant further study.

Invest - Interactive New Venture Examination and Sensitivity Test

Sensitivity Analysis of Change in Present Value
for 10 Pct. Change in Parameter Value

Item	Parameter	Delta Low	Delta High
1	Interest Rate	86320.	-86320.
2	Units Manufactured Pct.	340171.	-349640.
3	Average Inventory Pct.	10672.	-10672.
4	Engineering Expense Pct.	14326.	-14326.
5	Selling Expense Pct.	31171.	-31171.
6	Admin Expense Pct.	28652.	-28652.
7	Receivables Pct.	23221.	-23221.
8	Depreciation Period (Yrs)	5429.	-4415.
9	Other Investment Pct.	-5805.	5805.
10	Total Market Units	-238595.	234656.
11	Market Share Pct.	-238595.	234656.
12	Unit Price $	-594346.	574828.
13	Unit Mfg'd Cost $	340171.	-349640.
14	R + D Cost $	223254.	-224020.
15	Annual Plant + Equip $	84730.	-84730.

Product is Saw Devices Case B

Baseline Present Value = -733275.

Figure VI-8. SAW Devices Parameter Sensitivity

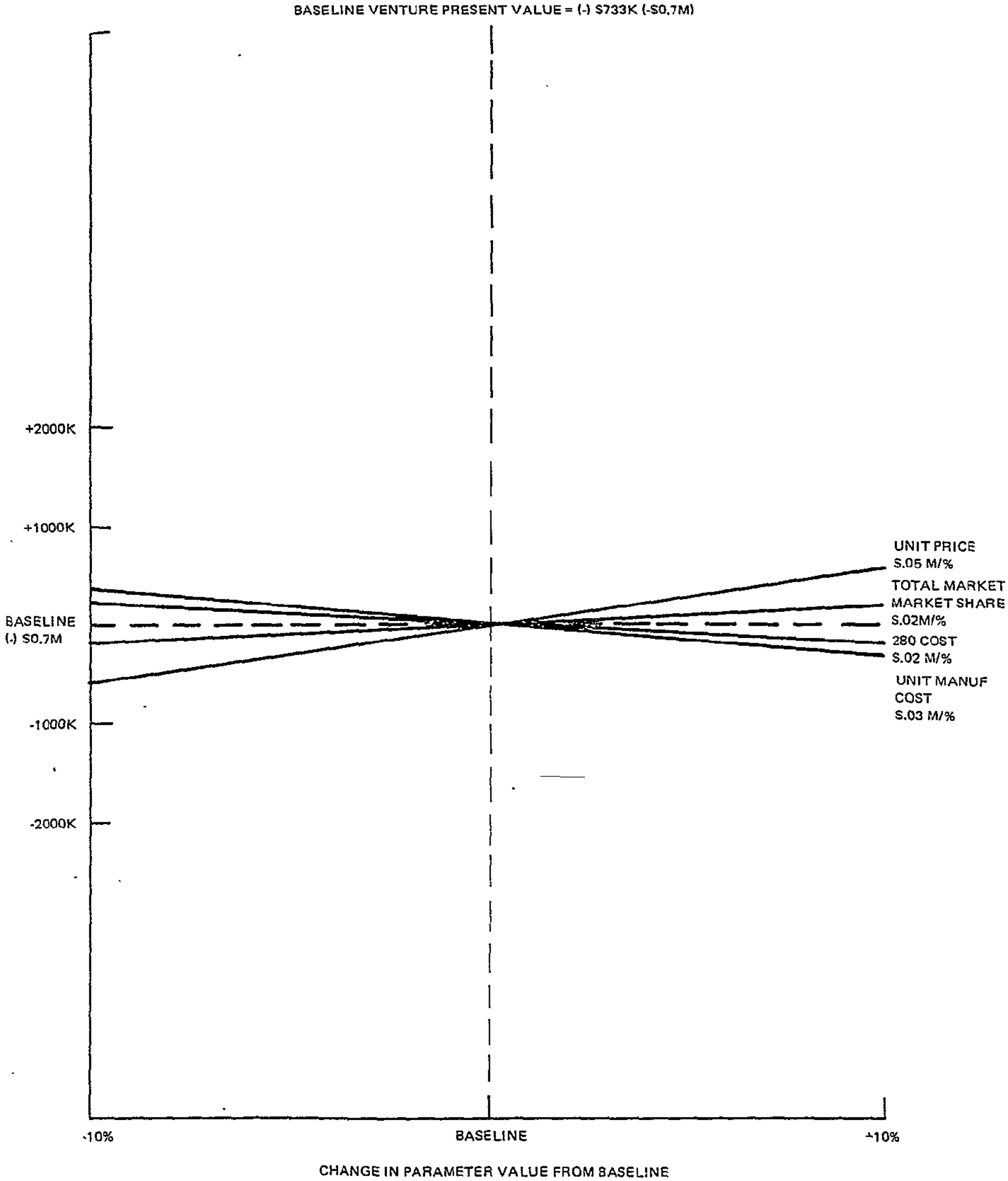

Figure VI-9. SAW Devices Parameter Sensitivity

GENERAL ELECTRIC

Space Division

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